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Design and Fabrication of a Board Cleaner Using an In-Line Slider-Crank Mechanism

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Abstract: *Board cleaning mechanisms are systems used to automatically clean boards (black or white) with the help of dusters mounted on frames. This work aimed at designing a completely mechanical, simple and affordable board cleaner using an in-line slider-crank mechanism. Revolving the crank engages the coupler in a reciprocating motion and sets the slider, in this case the duster in a translational motion. The translational motion of the slider wipes the board in a clockwise or anticlockwise rotation of the crank. Drudgery, time lost, the inconveniences of walking up and down the board to clean, and the likes of those using chalk and getting dirty or inhaling the dust generated when erasing blackboards by hand are few challenges to both teachers and students during lesson times. The in-line slider-crank board cleaner designed takes approximately 8s to erase a board expanse of 0.5m*^{2} *in two revolutions of the crank. The process of erasing with a slider-crank mechanism is fast and requires minimal assistance. Thus the in-line slider-crank board cleaner takes less time to erase boards compared to board erasure by hand.*

Keywords: *Four-bar mechanism**,** links, in-line slider-crank mechanism, board cleaner.*

I. Introduction

Until the recent use of whiteboards in Africa most especially the rural areas, the commonest teaching and learning equipment used in the classroom is the blackboard with chalk. The traditional technique of cleaning the blackboard is hand cleaning with a rag or duster and then clapped against a wall or a hard surface to get rid of the chalk dust on the duster. Thus, the traditional method of erasing black and whiteboards with the hand is time-wasting and a threat to the health of students and teachers. A board cleaning mechanism is a new technology which has evolved and used in present-day to fix the problem. Tumpala et al. [1] stated that the main objective of the current automatic blackboard duster is to enable an attachment for blackboards in the form of a power-driven erasing tool which can operate by closing a circuit switch and will thus, eliminate the drudgery of erasing blackboards by manpower. Kewate et al. [2] stated that a teacher or lecturer's effectiveness is affected when using blackboard in presenting to a class since he/she has to stop to clean the blackboard from time to time. This stoppage develops into a huge drawback as the size of the board and the expanse of coverage enlarges. Therefore, there is the need to design a mechanism to perform automatic cleaning functions on the boards to save time, energy and protect the health of both teachers and students. Thus, there will be a high degree of cleanliness, protection of health and reduction in the time used to clean boards as compared to hand erasing if board cleaning mechanisms are attached to boards. This solution is met in this work aimed at the design of a board cleaner using an in-line slider-crank mechanism, in that an attached handle is used to rotate the crank which translates the slider to erase the board instead of erasing by hand. Kewate et al. [2] designed an automatic board cleaner slider wipe type mechanism to clean the blackboard and collect chalk dust during a rub or wipe. Figure 1 is the cleaning mechanism designed by Kewate et al. [2]. The slider wipe type mechanism is made up of three sliders, two motors and three guide rails. The first and second sliders were connected by a cross guide rail installed on them. The guide rail can move in parallel to the third slider which is driven by two motors. One motor drives the left and right movement of the cross guide rail and the other motor drives the vertical movement of the third slider as a wipe system along with the guide rail to erase the blackboard. Sensors are also incorporated at the right top corners of the board to detect the end of the board and ensure the wiper comes back to its original position.

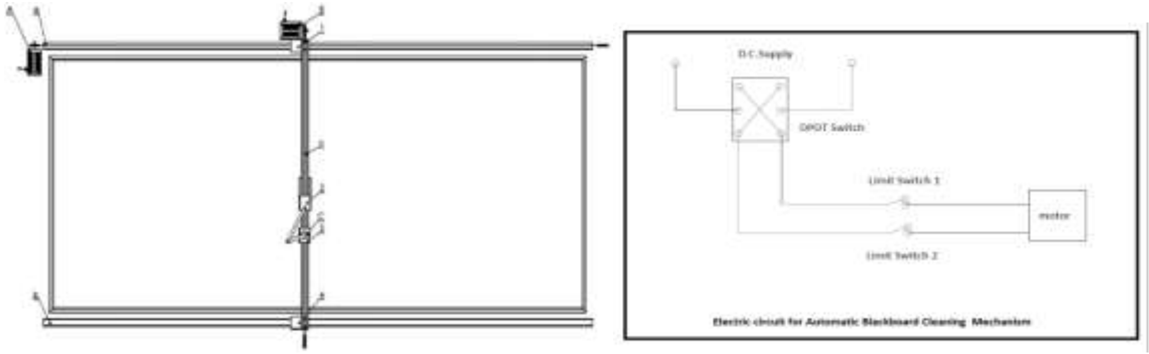


Figure 1: Automatic Board Cleaner and its Operating Circuit

Joshibaamali and Priya [3] in their work have stated that the duster machine can operate in three selectable operative modes. Figure 2 shows the automatic duster machine designed by Joshibaamali and Priya [3]. The first mode cleanses the left side of the board, the second mode cleanses the right side of the board and the third mode cleanses the whole area of the board. Their automatic duster machine also uses two stepper motors to move the duster in horizontal and vertical directions. A linear motor is used to move the duster in up and down directions. To detect the horizontal direction of the motor, an infrared transceiver is used. They also incorporated four limit switches to check the ends of the board. The main controller in the machine is made of a microcontroller programmed in a C language.

Figure 2: Automatic Duster Machine with Three Selectable Modes

Gangurde [4] designed a board cleaning system which used a rack and pinion mechanism to erase boards (black and white) powered by a DC geared motors. Figure 3 shows the 3D, side and front view of automatic board cleaning system by Gangurde [4]. The motors drive the pinions and convert the rotary motion of the pinions into linear motion on the rack which carried a connecting strip with a duster. Limit switches are used to stop the pinion and rotation of one gear clockwise and another anti-clockwise. A small water sprinkler was also used to spray water on blackboards only. He asserted that whiteboards do not require the sprinkler system. The motor connected to the wiper created the pressure to sprinkle the water on the blackboard which will save energy, time and eliminate the load on the motor. The clearance between the pinion and rack was adjusted by a back connecting strip using a toggle mechanism.

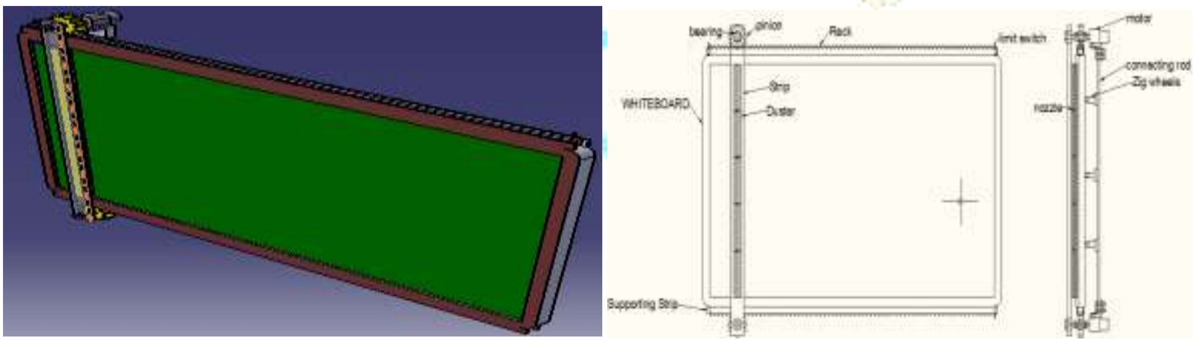


Figure 3: 3D, Side and Front View of Automatic Board Cleaning System

A DC Motor was connected through shaft coupled with a Double Slider Crank linked with rack and pinion to convert rotary motion into linear motion. A pinion is a circular gear and a rack is a linear gear bar. The application of rotational motion to the pinion will engage the rack to travel relative to the pinion to translate the rotational motion of the pinion into linear motion. The DC motor is connected to a power source to convert electrical energy into mechanical energy. When this happens, the pinion engages the rack and converts the rotary motion of the pinion into a linear motion of the rack. The rack is welded with the Steel rod with a duster attached. The linear motion of the rack connected with the steel rod performs the cleaning function on the board with the help of the attached duster [5]. Figure 4 shows the front and side view of blackboard cleaning system.

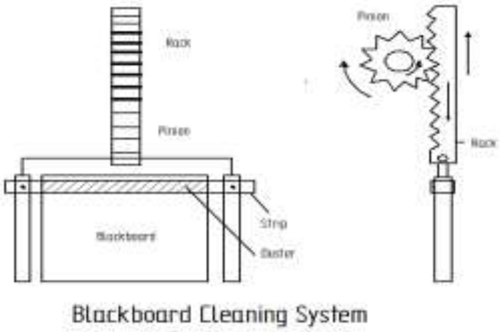


Figure 4: Front and Side View of Blackboard Cleaning System

A board is one of the fundamental visual aids in teaching and learning. Students learn better if instructors present lessons by different means, especially by visual means [6]. There are different types of boards in present day. Some types include; bulletin boards, chalk and white boards and interactive whiteboards or smart boards. Bulletin boards are surfaces or boards used for posting public notices or messages in schools or workplaces. Types of bulletin boards include; child-created, decorative, conceptual and interactive bulletin boards. White and chalk boards are the simplest and commonest teaching and learning aids. They provide a surface to support active learning where the teacher can engage students through problem-solving. Markers are used to write on whiteboards while chalks are for writing on the chalkboards. Interactive whiteboards also known as smart boards are large interactive boards or screens on which a computer and a projector are connected. The instructor or the user uses a special pen or his/her finger to interact with the computer desktop projected by the projector on the screen. Shah et al. [7] stated that the most effective and dominant method of delivering a lecture is PowerPoint Presentation. But there is no key difference in learning outcomes in the mode of presentation in PowerPoint rather than written on boards with the hand [8]. According to Karsenti [9], interactive whiteboards seem to introduce more complications for classroom coordination than achieving enhanced learning, and their potential for active teaching and learning are still being studied. Meo et al. [10] stated that teaching using both PowerPoint and the chalk or white boards together improves teaching and learning rather than using only one of them. Therefore even as we transition from the use of chalk and white boards to interactive whiteboards, there is a need to keep using the chalk and whiteboards to keep balance. A slider-crank mechanism is a four-bar mechanism that has three revolute or pin joints and a prismatic or sliding joint, used to convert rotary motion to linear motion and Vice versa [11]. The revolute and prismatic joints are also called pin and sliding joints respectively. There also two types of slider-crank mechanisms namely; offset and in-line slider-crank mechanisms. In an offset slider-crank mechanism, slider movement is not symmetric such that the crank and the slider are not on the same line and thus an offset distance is introduced. Whereas in the in-line slider-crank mechanism as the name suggests, the crank and the slider are on the same line. The type selected is the in-line slider-crank mechanism. It has three major parts namely; the crank, the coupler and the slider. The slider-crank mechanism is a type of four-bar mechanism. A four-bar mechanism is a class of mechanical linkage in which four links are pinned together to form a closed-loop to perform some useful motion [12]. For a planar motion in a kinematic system, the motions may be pure rotation, pure translation or complex motions. In a slider-crank mechanism, the crank is set in a rotational motion which engages the coupler in a reciprocating motion and in turn translates the slider. A simultaneous combination of the rotational motion of the crank and the translational motion of the slider about the crank pivot makes the motion a complex motion [13]. One important factor in mechanism analysis is the number of degrees of freedom. The degree of freedom of a mechanism is the number of free input links needed to correctly arrange the output links about the ground link of the mechanism. The number of degrees of freedom of a mechanism is referred to as the mobility of the mechanism. The mobility of a mechanism is denoted by the letter M. Gruebler developed an equation to solve for the number of degrees of freedom for planar linkages with common joints. Thus Gruebler's equation for mobility is given by

$$M=3L - 2J - 3G$$

Where
M = mobility or degree of freedom
L = number of links
J = number of joints
G = number of ground links [14].
For a slider-crank or four-bar mechanism, L = 4, J = 4 and G = 1
$M = 3(4) – 2(4) – 3(1)$
$M = 1$
The mobility of a slider-crank or four-bar mechanism is one (1) and can thus be interpreted that the slider-crank mechanism needs just one driver to be set in operation [11].

II. Method

2.1 Design of the In-Line Slider-Crank Board Cleaner

The in-line slider-crank board cleaner was designed by Solid Edge ST8 software. The in-line slider-crank mechanism has three major parts namely; the crank, the coupler and the slider (duster). The crank, the coupler and the slider are 0.45 m, 1.1 m and 0.48 m long respectively and was used on a whiteboard sheet made of white Formica with dimension 0.5 m x 1 m. A supporting surface made of wood was used to serve as a base to hold the whiteboard sheet and a point of attachment of the crank for ease of rotation. The in-line slider-crank mechanism is made of mild steel rod. Figure 5 shows the design of the in-line slider-crank board cleaner. A duster is attached to the slider of the in-line slider-crank mechanism to facilitate the cleaning process. The duster material used is foam. A handle made of mild steel rod is attached to be used as a driver instead of an actuator (DC motor) to set the mechanism in operation.

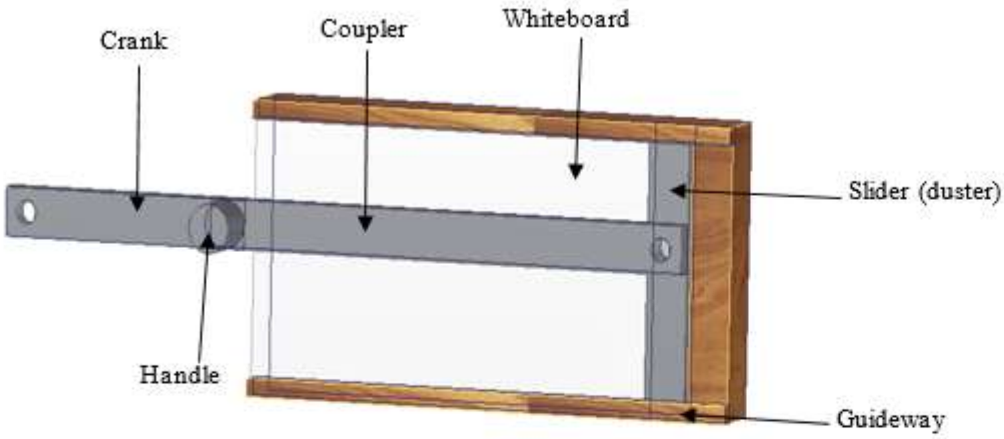


Figure 5: In-Line Slider-Crank Board Cleaner Design

2.2 Fabrication of the Board Cleaner

The in-line slider-crank mechanism was first assembled according to design specification and a duster material attached to the slider. A guideway was also attached to the board and well fastened. The in-line slider-crank mechanism with the attached duster was then well positioned on the board as specified in design. The crank was fastened to a supporting surface and a sliding joint created between the slider and the guideway to allow the slider to freely translate when the crank is rotated. The handle was gently placed closed to the joint of the crank and the coupler to be used as an actuator to erase the board.

III. Results and Discussion

3.1: Results

Figure 6 shows the fabricated in-line slider-crank mechanism.

Figure 6: In-line Slider-Crank Board Cleaner

3.2: Working Principle of the In-Line Slider-Crank Board Cleaner

The in-line slider-crank mechanism works on the principle of reciprocating engines where the rotational motion of the crank is converted to translational motion of the piston which pushes the piston from the Bottom Dead Center to the Top Dead Center. The same principle is applied in the design of the in-line slider-crank board cleaner. Here the board is taken as the cylinder and the piston as the slider which is the duster in this case. A guideway was provided to create a sliding joint. Rotating the crank engages the coupler in a reciprocating motion and sets the slider which is the duster in translational motion. The translational motion of the slider wipes the board in a clockwise or anticlockwise rotation of the crank.

3.3: Kinematic Analysis of an In-Line Slider Crank Mechanism

Kinematics is the study of motion of objects without considering the forces causing the motion. The kinematic analysis involves the determination of position, velocity, and acceleration of a mechanism. Figure 7 shows the in-line slider-crank mechanism with some parameters useful in the analytical computation of the position, velocity and acceleration equations. For an in-line slider-crank mechanism, there is no offset distance and hence B_1 is zero.

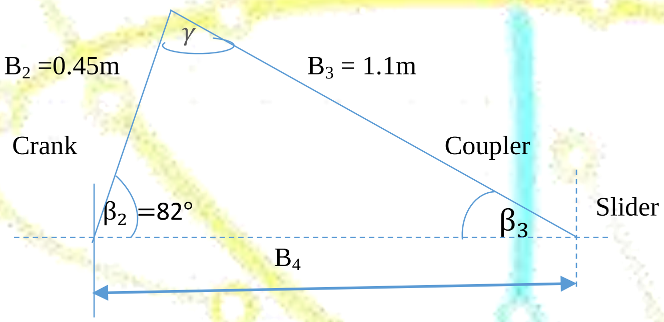


Figure 7: Kinematic Diagram of an In-Line Slider-Crank Mechanism

3.4: Position Analysis

The position of the in-line slider relative to the pivot of the crank mechanism must be determined. For an in-line slider-crank mechanism shown in Figure 7, the following position equations are taken from Myszka [11] and modified.

$\beta_3 = \sin^{-1}(\frac{B_2 \sin \beta_2}{B_3})$ Angular position Eqn. 1

$B_4 = B_2 \cos \beta_2 + B_3 \cos \beta_3$ Linear position Eqn. 2

$\gamma = 180° - (\beta_2 + \beta_3)$ Eqn. 3

From figure 7 above,

β_2 = 82°

B_2 = 0.45m

B_3 = 1.1m

3.4.1: Angular Position

From equation 1,

$\beta_3 = \sin^{-1}(\frac{B_2 \sin \beta_2}{B_3})$

$\beta_3 = \sin^{-1}(\frac{0.45\sin(82)}{1.1})$

β_3 = 23.9°

3.4.2: Linear Position

From equation 2

$B_4 = B_2\cos\ \beta_2 + B_3\cos\ \beta_3$

B_4 = 0.45cos (82) + 1.1cos (23.9) = 1.07m

From equation 3, we take β_3 = 82°

$\gamma = 180° - (\beta_2 + \beta_3)$

γ = 180° – (82° + 23.9°) = 74.1°

Given a linear position equation, $B_4 = B_2\cos\ \beta_2 + B_3\cos\ \beta_3$ Eqn. 2

B_2 = length of crank = 0.45m

B_3 = length of coupler = 1.1m

β_3 is the imbalance angle corresponding to B_3 the length of the coupler

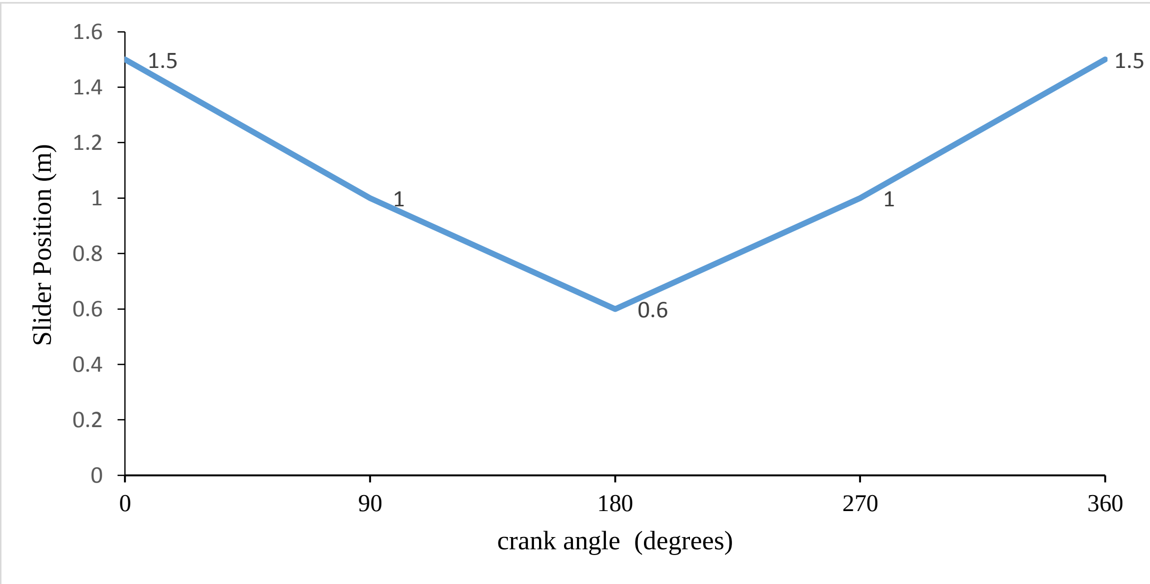
β_2 is the imbalance angle corresponding to B_2 the length of the crank

β_3 is kept at 23.9° while varying the crank imbalance β_2

Then the linear position B_4 can be found at different crank imbalance angles

Table 1: Angular and linear positions of an in-line slider-crank mechanism

Crank Imbalance Angle β (degrees)	Linear Position B_4 (m)
0°	1.5
90°	1.0
180°	0.6
270°	1.0
360°	1.5



Graph 1: Kinematic Position Graph of an In-line Slider-Crank

3.5: Velocity Analysis

The velocity equations are derivatives of the following position equations

$\beta_3 = \sin^{-1}(\frac{B_2 \sin \beta_2}{B_3})$ Angular position Eqn. 1

$B_4 = B_2\cos\beta_2 + B_3\cos\beta_3$ Linear position Eqn. 2

The velocity equations as derived from equations 1 and 2 are

$\omega_3 = -\omega_2(\frac{B_2 \cos \beta_2}{B_3 \cos \beta_3})$ Angular velocity Eqn. 4

$V_4 = -\omega_2 B_2 sin\beta_2 + \omega_3 B_3 sin\beta_3$ Linear velocity Eqn. 5

Modified from [11].

3.5.1: Angular Velocity

From equation 4

$\omega_3 = -\omega_2(\frac{B_2 \cos \beta_2}{B_3 \cos \beta_3})$

Knowing B_2 = 0.45m, B_3 = 1.1m, β_2 = 82°, and β_3 = 23.9°

Given an angular velocity of the crank to be 60rpm = - 1rad/s. Thus $\omega_2 = -1 rad/s$

$\omega_3 = -(-1)\left(\frac{0.45 \cos (82)}{1.1 \cos (23.9)}\right)$ = 0.06 rad/s

3.5.2: Linear Velocity

From equation 5

$V_4 = -\omega_2 B_2 sin\beta_2 + \omega_3 B_3 sin\beta_3$

V_4 = - (- 1) x 0.45sin (82) + (0.06) (1.1) sin (23.9)

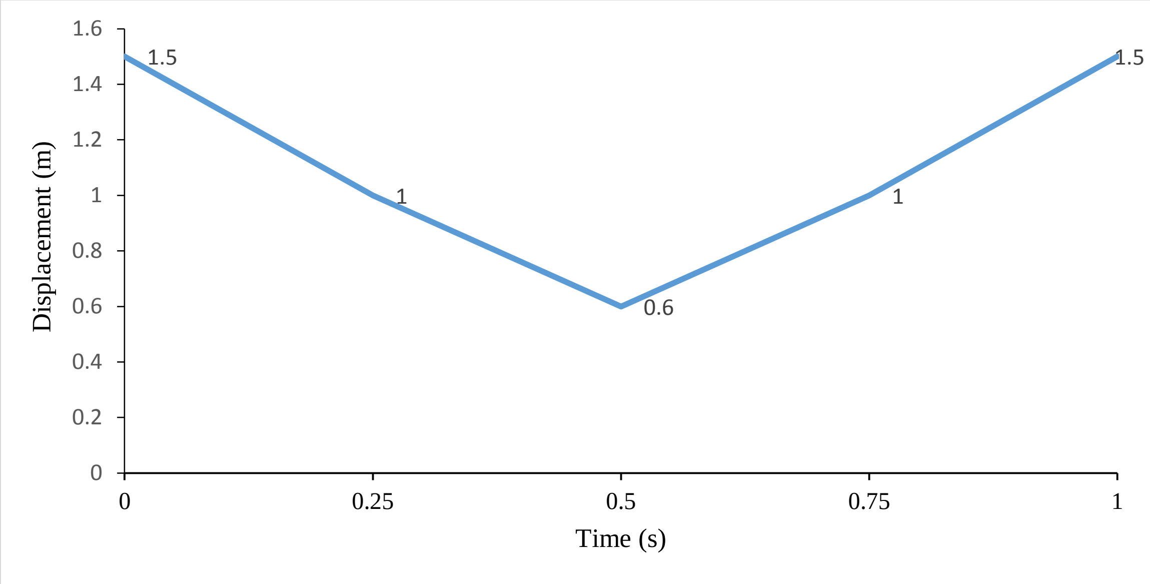
V_4 = 0.47 m/s

Time of travel of crank through an angle θ is given by t = $\frac{\theta \times 60}{360 \times \omega_2}$ (s) Eqn. 6

Given an angular velocity of the crank to be 60rpm, then the time taken for the crank to travel through an angle θ, is t = $\frac{\theta \times 60}{360 \times 60}$ (s).

Table 2: Time of travel and displacement of an in-line slider-crank mechanism.

Crank Imbalance Angle β (degrees)	Time (s)	Displacement (m)
0°	0.00	1.5
90°	0.25	1.0
180°	0.5	0.6
270°	0.75	1.0
360°	1	1.5



Graph 2: Displacement - Time Graph of an In-Line Slider-Crank

3.6: Stress Analysis

Stress σ, of a link is the force per unit cross sectional area of the link.
The links of the slider-crank mechanism have two end conditions namely; link with both ends pinned and link with one end fixed and the other pinned.
Euler's equation for critical load of a column with both ends pinned is given by

$$P_{cr} = \frac{\pi^2 \times EI}{L^2}$$

Eqn. 7

Where

P_{cr} = Euler's critical load

L = length of link

E = young modulus of material = 200 GPa for steel [15].

I = the moment of inertia of a square pipe I = $\frac{a^4 - b^4}{12}$

Eqn. 8

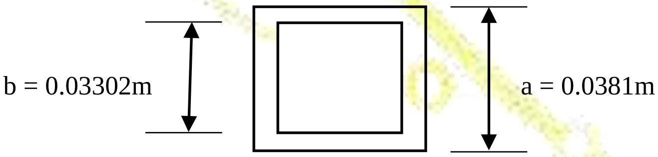


Figure 8: Moment of Inertia of a Hollow Square Pipe

For the bar in use, a = 0.0381m and b = 0.03302m as measured, (thickness, t = 0.1").

I = $\frac{0.0381^4 - 0.03302^4}{12}$ = 7.653x10^{-8} m^4

The critical load for which a structural member (link) of length 1.1m can fail is $P_{cr} = \frac{\pi^2 \times 200 \times 10^9 \times 7.653 \text{ x } 10^{-8}}{1.1^2}$ =

124846.42 N.

Euler's equation for critical load of a column with one end fixed and the other pinned is given by $P_{cr} = \frac{2.07\pi^2 \times EI}{L^2}$

Eqn. 9

The critical load for which a structural member (link) of length 0.45m can fail is

$$P_{cr} = \frac{2.07 \times \pi^2 \times 200 \times 10^9 \times 7.653 \text{ x } 10^{-8}}{0.45^2} = 1544211.46 \text{ N}$$

Critical stress is given by $\sigma_{cr} = \frac{P_{cr}}{A}$ Eqn. 10

Area of the hollow square pipe, $A = a^2 - b^2$

$A = 0.0381^2 - 0.03302^2 = 0.000361m^2$

Critical stress for strut with both ends pinned (coupler)

$$\sigma_{cr} = \frac{124846.42}{0.000361}$$

$$\sigma_{cr} = 3.458 \times 10^8 \text{ N/m}^2$$

Critical stress for strut with one end fixed and the other pinned (crank)

$$\sigma_{cr} = \frac{1544211.46}{0.000361}$$

$$\sigma_{cr} = 4.278 \times 10^9 \text{ N/m}^2$$

Moment of inertia, critical load and stress equations are modified from [15].

3.7: Time Response of the Board Cleaner

A board of dimension 0.5 m x 1 m was used. Erasing by hand, it takes a minimum of 26 s to completely clean the board area. The in-line slider-crank board cleaner requires two revolutions for effective erasure and the time computed to be approximately 8 s. The following data was recorded while testing the time response for effective cleaning of the in-line slider-crank board cleaner.

Table 3: Time response of the in-line slider-crank board cleaner

Number of trials K	Time of one revolution (s)	Average time of k trials (s)	Average time of effective erasure (s)
1	4.21	4.155	8.31
2	4.12		
3	3.99		
4	4.25		
5	3.97		
6	4.47		
7	4.05		
8	4.15		
9	4.36		
10	3.98		
Total	41.55		

The average time of erasure of a board of area $0.5m^2$ using the in-line slider-crank board cleaner is observed to be 8.31s while testing its time response. Cleaning the board of area 0.5 m^2 by hand takes a minimum of 26 s. This implies the board cleaner has reduced the time of erasure to about three times the time of erasure by hand. The in-line slider-crank board cleaner has a wide erasure area with a high cleaning accuracy and requires a small pressing force to operate. However, it does not erase only desired unwanted marks on the board or a small portion of the board but cleanses the board expanse in a wipe.

IV. Conclusion

A board cleaner has been designed and fabricated. It is an in-line slider-crank board cleaner with duster attached to the slider to perform erasure functions on whiteboards. It can erase a board expanse within a very short duration. It can be used in schools, colleges or universities to help in the erasure of boards to reduce time spent while cleaning the boards by the hand. The in-line slider-crank board cleaner is made simple in design, economical in cost, and conservative in time and energy.

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