Development of a Push Crank Mechanism Off-Road Wheel Chair

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Abstract — This work is aimed at proffering solution to the challenges encountered from wheelchair usage. These challenges include; shoulder and upper extremity injuries caused by the un-natural motion of pushing a conventional manual wheelchair. Unlike the conventional manual wheelchair, the push crank wheelchair has no push rims. These push cranks are attached to the sprockets by means of bolts and nuts and held in position by means of return springs. This report however covers, in detail the procedure of material selection, design analysis and cost accounting of the whole project. The method used in the design gives room for ease of dismantling and assembly. The off-road wheelchair was tested, and a satisfactory speed of 0.44m/s was recorded.

Key Words — Off-road wheelchair, push crank mechanism, shoulder, upper extremities.

I. INTRODUCTION

Strolling down a beach, hiking up a mountainside trail, simply walking down a flight of stairs, these are things many of us take for granted. There are, however, a large number of people who do not take these activities for granted. This group is the 1.7 million Americans and 42.5 million people worldwide confined to a wheelchair. Though they may come from all different parts of the world, the reasons they are restricted to a permanent sitting position remain similar. Some well-known reasons include old age, paraplegia and quadriplegia. Other reasons include those, which may be unfamiliar to most people. These reasons include mobility disabilities such as spinal bifida, cerebral palsy, and muscular dystrophy. Regardless of their disabilities, these people still need to get up each morning and live life. For most, this can only be possible with the help of a wheelchair (Redman customer service representative, personal communication, May, 1996).

Wheelchair is a device that can enable and empower a person with a disability to live an independent life. It is important that the design and setup of a wheelchair properly suit the user's needs; the most important being comfort and health. As anyone who has ever sat in a seat for an extended period can attest to, in order to provide comfort, continual repositioning of oneself is required. In addition to comfort, the health and well-being of the wheelchair user is also of concern. The challenge of accessing off-road or difficult terrain by the wheel chair users has been of serious concerns which need to be addressed, so that they can as well participate in any activities that are going on in these areas.

Wheelchair is a device propelled either manually (by turning the wheels using hands) or via various automated systems. Wheelchairs areused by people for whom walking is difficult or impossible due to illness (physiological or physical), or injury. People with both sitting and walking disability often need to use a wheel bench. A basic standard manual wheelchair incorporates a seat and back, two small front (caster) wheels and two large wheels, one on each side, and a foot rest. There are many types of wheelchairs, and they are often customized for the user's needs. The seat size (width and depth), seat-to-floor height, seat angle (also called seat dump or squeeze) relative to the horizontal plane, footrests/leg rests, front caster outriggers, adjustable backrests, controls, and many other features can be customized for the user based on his peculiarity or severity of his deformity (Kroemer, 1989).

Without wheelchair, many disabled people can become prisoners in their own homes, unable to access education or employment. That is why the estimated 25 million people in the world that need a wheelchair, but not have one, are often among the most disadvantaged and poor in the society (Redman customer service representative, personal communication, 1996).

In many factory or plant environments, people confined to wheelchairs have difficulty completing the tasks that are required of them, specifically in the off-road or difficult terrain. There is need to develop a workable and economical alternative to existing off-road wheelchairs, whose main drawbacks are cost of production and maintenance, mobility and stability, ease of operation and speed. Millions of people live with mobility-related disabilities that require the use of wheelchair, walker, or other mobility equipment. Individual with mobility limitations face a myriad of physical and psychological challenges associated with daily wheelchair use. For example, the simple tasks of walking down off-road for a site seeing present real physical challenges for many people with mobility-related disabilities. Many of these individuals are unable to participate in activities due to their disabilities, or risk injury by attempting the activities without adequate equipment. In addition to these challenges, wheelchair users also suffer from social and psychological challenges associated with wheelchair use. For example, wheelchair users typically are at a lower vantage point than their standing peers, which means that wheelchair users are accorded with little respect in many social situations. This lower vantage point create real or perceived disadvantage in many social situations. These physical and sociological challenges may lead wheelchair users to feel helpless or frustrated by their limitations. Existing wheelchairs and other mobility equipment do not adequately address the various physical and psychological challenges faced by those with mobility-related disabilities. This project is directed to off-road or difficult terrain wheelchair, which allows an occupant of the wheelchair to walk in difficult terrain safely without need of any assistance.

II. Literature Review

The first clear proof of a wheelchair, however, is from a Chinese image engraved in AD 525. Any subsequent history of the wheelchair is hard to document until 1595. This was the year in which an artist drew a sketch of the Spanish King, Philip II of Spain (1527 – 1598), seated in a chair that had small wheels mounted at the end of each leg. Features of the chair included a raised platform for the King’s legs and an adjustable back rest.

King Philip’s chair was not self-propelled; he relied on a courtier or servant to push it. The first recorded instance of a disabled person with independent mobility was in 1655 when Stephen Farfler, a paraplegic watchmaker, built a robust-looking chair on a three wheel chassis. Attached to either side of the single front wheel were handles that Stephen turned to propel himself forward.

The next development was a chair invented in 1783 by John Dawson. Dawson worked in Bath, England, where many invalids travelled to drink and bathe in the spa water. Dawson’s “Bath” chair, with its third wheel that the occupant could steer by using an attached rigid handle, was a great success. There were a number of versions, some of them open, some with hoods and glass fronts, but they all had to be pushed from behind or pulled by a small horse or donkey.

During the nineteenth century, wheelchairs became less cumbersome and more comfortable. As a result, some users were able to turn the large rear wheels with their hands, although this could be unpleasant if the chair ran through a patch of mud. The problem was solved in 1881 when manufacturers began to add a second rim with a smaller circumference to each wheel. These rims kept the hands clean and were known as push rims (Muvdi and McNabb, 1990).

By the beginning of the twentieth century, wheelchairs had developed still further and boasted wire-spoke wheels, adjustable seat backs, and moveable arm and foot rests. There were also lightweight models made of wicker mounted on metal frames.

By 1916, British engineers had produced the first motorized wheelchair, although the majority of users remained in manual versions, which were becoming much cheaper. Despite this, the chairs were still rigid and difficult to store and transport, particularly in cars. But in 1932, a Los Angeles engineer named Harry Jennings designed and built a folding wheelchair for his friend, Herbert Everest. The two men immediately saw the potential for this invention and established a company to mass-produce the new portable chairs. These were the forerunners of the wheelchairs in common use today.

Early chairs were made of wood, were very heavy by today's standards, and had tall backs. They provided very limited mobility; most users couldn't even push themselves and had to rely on other people to wheel them around.

Early power chair used belts in the drive-train. The motor turned a rotor which had a belt wrapped around it, and the belt transmitted the power to the wheels. Today's chairs use direct drive, meaning the motor turns gears which in turn move the power through a gear transmission to the wheels. Direct drive is more reliable and needs less maintenance.

Power chairs were actually once called “electric chairs”, until marketers realized that the public thought of electric chairs as machines of execution. The early power chairs were manual chairs with batteries and drive mechanisms jury-rigged on. The chairs were bulky and difficult to navigate with. Designers have since fixed those problems, and modern power chairs have all their elements integrated into a coherent system. While the first power chairs used electric power only for moving the wheels forward, today's systems include powered adjustments for seats, foot rests, back pads, and head rests (Chris and Daniel, 2007)

The company Everest and Jennings dominated the wheelchair industry during the mid-20th Century. They had so much market power that they faced charges of setting the prices too high, and the US Department of Justice brought an antitrust suit against them. New companies came up with innovative designs, and expanded the range of options for wheelchair users.

Types of Wheel Chair

There are different categories of wheelchair. Wheelchairs can be categorized according to rigidity of the frame for example rigid frame wheelchairs and folding frame wheelchairs.

Rigid Frame Wheelchairs

Generally, a rigid frame wheelchair will consist of a welded frame on which the person sits. The back of the chair has the ability to fold down, and the wheels have a quick release mechanism to enable easy transportation and storage of the wheelchair. Most rigid frame wheelchairs are made from either aluminum or titanium, but there are some specialized wheelchairs made from carbon fiber. A lightweight rigid frame wheelchair can weigh as little as 10lbs without its wheels. As the chair is lighter, it will be easier to push, therefore putting less stress on your shoulder joints. As rigid frame wheelchairs have less moving parts, they are generally stronger than folding wheelchairs and last longer.

Folding Frame Wheelchairs

A folding frame wheelchair is a wheelchair whose frame is collapsible sideways by the use of an X mechanism in the frame. This mechanism is lockable, and the wheelchair folds on release of two locking levers on the chair. Because the folding wheelchair has an X mechanism, locking levers and re-enforcing struts, it is usually heavier than a rigid frame wheelchair. Folding wheelchairs also have movable footrests which allow the chair to collapse. Early folding chairs were made from steel, but now days they are made from aluminum or titanium. As there are more moving parts in the folding chair, and movable joints, the chair is not as durable as a rigid frame wheelchair. This in turn will mean a higher maintenance is required to keep the wheelchair in good condition.

A lot of work has been done on wheelchair design. For instance, Steve and Victoria (1995) worked on a novel chain-drive mechanism for an off-road wheelchair. The limitation of the design include; large storage space when not in use, the design restrict of user from maneuvering his way through normal house doors and tight corners, and difficulty in transporting the wheelchair from one place to the other.

Chris and Daniel (2007) designed a wheelchair using the materials available in the third world. The wheelchair was designed for easy transportation, lighter weight, ease of maneuvering through doors and tight corners, to occupy little space for easy storage, and to use the available local raw materials. However the limitation for this design include; the wheelchair is restricted to a confirmed area such as smooth path which limits the social, recreational, and sport life of the patent, apart from that the user also need a care taker to assist him in difficult terrains and packaging.

It is worthy of note that the Computer Aided Design (CAD) System is also being used for wheel chair manufacture. Among works involving application of CAD for wheelchair design, Ayodeji and Adejuyigbe (2008) developed CAD software for wheelchair design capable of designing customized wheelchair for any category of wheelchair bound person using anthropometric data of the person within 2minutes several other notable researches had also been done on the wheelchair in recent times to ensure ease of design, safetyof users and to modify existing designs for comfort of users. Armstrong and Buning (2004) studied wheelchair users attitudes, knowledge, and behavior when riding fixed-route transportation with the objectives of discovering the wheelchair transportation accessibility barriers that are unique to fixed route transportation and determining the relationship between barriers and variables such as type of wheelchair, age of wheelchair user, and size of public transit system that may have an effect on these barriers.

Betsy (2005) designed a manual wheelchair to ease shoulder strain and transfer. This wheelchair was design to combat some life's punishments for being a wheel chair user. This include; shoulder and upper extremity injuries caused by the un-natural motion of pushing a conventional manual wheelchair. And, even more upper extremity injuries caused by the need to transfer in and out of a wheelchair using arms only. This was accomplished using a push crank instead of a push rims. The limitation of this design however is the positioning of the rear wheels; the inclined position of the wheels will increase the pressure on the sides of the tires which will increase the wearing rate of the tires.

III. METHODOLOGY

A. Design Considerations

Some factors that influence the design of components were considered in order to understand the effect and influence of each factor on the frame, the shaft and the push crank, and also in combination with other factors, so that the final design will be based on proper application of these factors. These factors are; appropriate material selection for components; strength and rigidity of construction; satisfactory performance of mechanism; reliable method of fabrication; ease of maintenance and repair; safety requirement, and economic consideration.

The design drawing for consideration is as shown in fig 1, while the assembly drawing is depicted in fig 2. The part and other detail drawings are placed in the appendix of this write up which are functions of the design parameters got in the subsection of this paper.

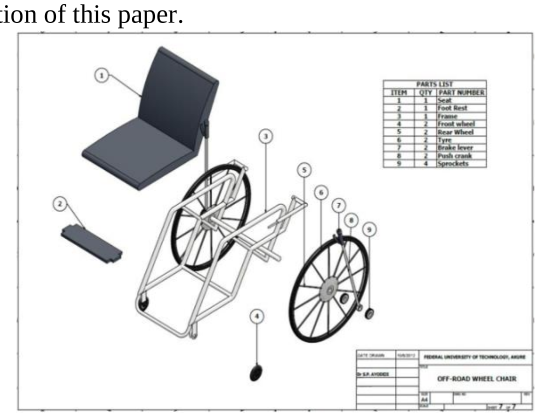


Fig. 1. Exploded view of Off-road Wheelchair.

Fig. 2. Assembly drawing of Off-road Wheelchair.

The components of the wheelchair as shown in figure 1 include the followings;

The frame

The brake system

The shaft

The front wheels

Push cranks

Sprockets

The Frame

The frame of the wheelchair is constructed of 3.25inch diameter mild steel tubing. The frame is continuously formed by bending method; it has a total length of about 0.7m, width of 0.41m and height of about 0.45m from the floor to the seat.

Dimension of the Frame Length

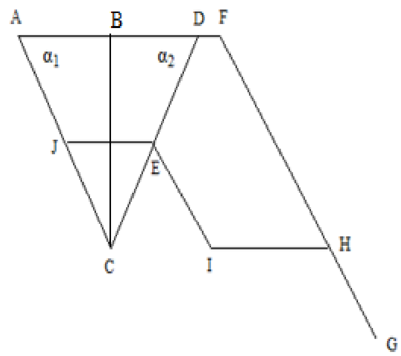


Fig. 3. Pipe frame length dimension.

Determination of the length of the rod AC from figure 3.

$$lineBC = \frac{L}{2} = \frac{476}{2} = 238mm$$

$$lineAB = \frac{AD}{2} = \frac{508}{2} = 254mm$$

Therefore, line AC is given as;

$$AC^2 = AB^2 + BC^2 \quad (1)$$

$$AC = \sqrt{AB^2 + BC^2} = 348.08mm$$

For the angle $\propto_1$,

$$\tan \propto_1 = \frac{BC}{AB}; \propto_1 = \tan^{-1}\frac{238}{254} = 43.14^{\circ}$$

Determining the length of the rod CD

$$line\ BC = BD = 254mm$$

$$CD^2 = BD^2 + BC^2$$

$$CD = \sqrt{BD^2 + BC^2} = 348.08mm$$

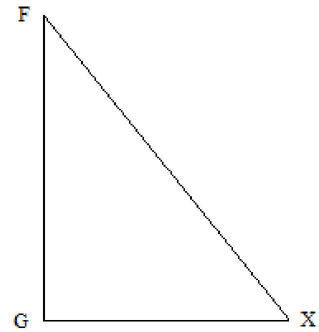
For the angle $\propto_2$,

$$\tan \propto_2 = \frac{\mathrm{BC}}{\mathrm{BD}};\ \propto_2 = \tan^{-1}\frac{238}{254} = 43.14^{\circ}$$

Determining the length of the rod DE

$$lineDE = AJ = CJ = CE = \frac{CD}{2} = 174.04mm$$

Determining the length of the rod FG

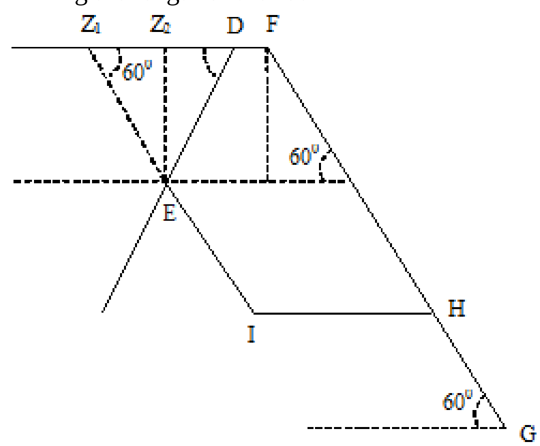


$$angle \propto_3 is\ given\ to\ be\ 60^{\circ}$$

$$\sin \propto_3 = \frac{L - C_l}{FG} = \frac{476 - 100}{FG} = \frac{376}{FG}\ (C_l = Clearance)$$

$$FG = \frac{376}{\sin 60} = 434.17mm$$

Determining the length of the rod DE



From the triangle DEZ_2;

$$EZ_2 = DE \sin \propto_2 = 174.04 \sin 43.14 = 119.01mm$$

From the triangle Fm_1m_2; $\sin 60 = \frac{Fm_1}{Fm_2}$;

$$Fm_2 = \frac{119.04}{\sin 60} = 137.45mm$$

$$lineEI = m_2H (parallellines)$$

$$\therefore EI = FG - Fm_2 - HG \qquad (HG = 100mm)$$

$$EI = 434.17 - 137.45 - 50 = 246.72mm$$

For the angle $\propto_4$,

$$angle\beta = 180 - 60 - \propto_2;\ \beta = 180 - 60 - 43.14 = 76.86^{\circ}$$

$$\propto_4 = \beta = 76.86^{\circ} \quad (oppositeangles)$$

Determining the length of the rod HI

From the triangle DEZ_2,

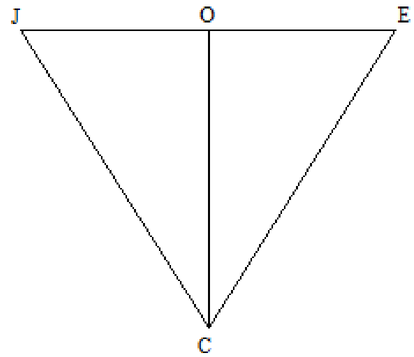
$$DZ_2 = \frac{EZ_2}{\tan \propto_2} = 126.99mm$$

From the triangle EZ_1Z_2; $Z_1Z_2 = \frac{EZ_2}{\tan 60} = 68.7mm$

$$\therefore HI = Z_1Z_2 + DZ_2 + DF;$$

$$HI = 245.69mm$$

Determining the length of the rod JE



Line CE = CJ = 174.04mm

$$\propto_{11} = \propto_1 = 43.14^{\circ}$$

$$\propto_{21} = \propto_2 = 43.14^{\circ} (corresponding angles)$$

For line OE,

$$OE = 174.04 \cos 43.14^{\circ} = 126.99mm$$

$$line\ OE = JO = 126.99mm (similar triangles)$$

$$therefore; JE = OE + JO = 253.99mm$$

FORCE ANALYSIS OF THE FRAME

Determining the force acting on the supporting rods AC and CD (Fig. 4)

$$P = 92kg$$

$$P_1 = P_2 = \frac{p}{4} = 23kg$$

The load is shared equally between the supports at point A; the load P_{11} is given as:

$$\beta_1 = 90^{\circ} - \propto_1 = 90^{\circ} - 43.14 = 46.86^{\circ}$$

$$\cos \beta_1 = \frac{P_1}{P_{11}};\ P_{11} = \frac{23}{\cos 46.86^{\circ}} = 33.64kg$$

$$\therefore load P_{11} = 329.64N$$

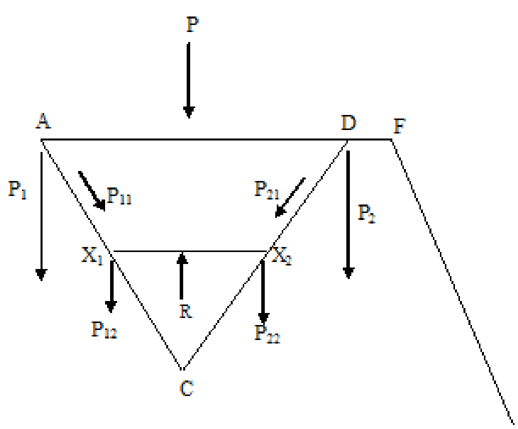


Fig. 4. Force Analysis of the Frame

Since $\propto_1 = \propto_2$, then $P_{11} = P_{21} = 329.64N$

$P_1 = P_2 = P_{12} = P_{22} = 329.64N$ (parallel forces with alternate angle)

Calculating for the reaction R

$R = P_{11} + P_{21} = 659.28N$ (Sum of downward forces is equal to sum of upward forces)

STRESS ANALYSIS OF THE ROD JE

The reaction R is given as 659.28N.

Bending stress on the rod JE, the bending equation is given as;

$$\frac{M}{J} = \frac{\delta}{y} = \frac{E}{R} \quad (2)$$

$$\delta = \frac{M}{Z} \quad (3)$$

$$Z = \frac{I}{y} \quad (4)$$

Z for the hollow pipe is given as;

$$Z_{XX} = Z_{YY} = \frac{\pi}{32}\left(\frac{d^4 - d_1^4}{d}\right) \quad (5)$$

Where;

M = bending moment acting at given section; δ = bending stress; I = moment of inertial of the cross-section about the neutral axis; y = distance from the neutral axis to the extreme fiber; E = young's modulus of the material of the beam; R = radius of curvature of the beam; Z= sectional modulus of the pipe; d = outer diameter of the pipe, and d_1 = inside diameter of the pipe.

The bending moment at J is given as;

$$M_J = P_{21} \times JE - R \times JO = 32.964Nmm$$

Bending moment at point E is given as;

$$M_E = R \times OE - P_{11} \times JE = 32.964Nmm$$

Sectional modulus for the hollow pipe; (Khurmi, 2005)

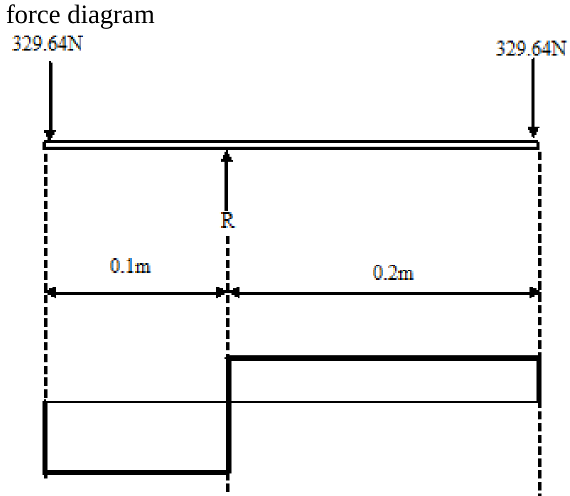
$$Z = \frac{\pi}{32}\left(\frac{d^4 - d_1^4}{d}\right) = \frac{\pi}{32}\left(\frac{0.0261^4 - 0.0251_1^4}{0.0261}\right) = 2.53^{-7}$$

From equation 3 the bending stress is then given as,

$$\sigma = \frac{M}{Z} = \frac{32.964}{2.53^{-7}} = 21871.75Pa$$

Since the bending stress is small, the design is safe as shown in Fig. 5.

Shear force diagram



Bending Moment diagram

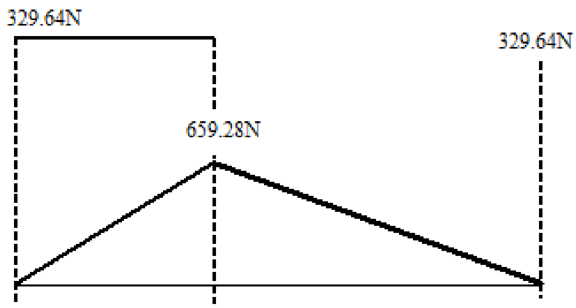


Fig. 5. Shear force and bending moment diagram.

THE BRAKE SYSTEM

There are four principal braking systems which can be used for this design, this include; coaster, caliper, disc, and drum brakes. The caliper braking system of a mountain climber bicycle is taken and adjusted for this design. It consists of a pair of arms that are pivoted together and fitted with brake pads. These arms close onto the metal wheel rims in a scissor-like motion. They are controlled by hand levers mounted on the push crank handle that connect to the arms by way of cables. Caliper brakes are available with either side-pull or center-pull cables. Side-pull brakes will be used because their braking force is easily feathered (adjusted minutely) (David *et al*, 1996)

THE REAR AXLE

This design employed two independent rear axles which are fitted into the roller bearings of the rear mountain bike wheels which thenpassed through hollow pipes and held in place by nuts. The wheels are placed in a forward position which placed the axle closer to the anatomical hip joint instead of somewhere behind it for better balance and performance (Timings, 1989).

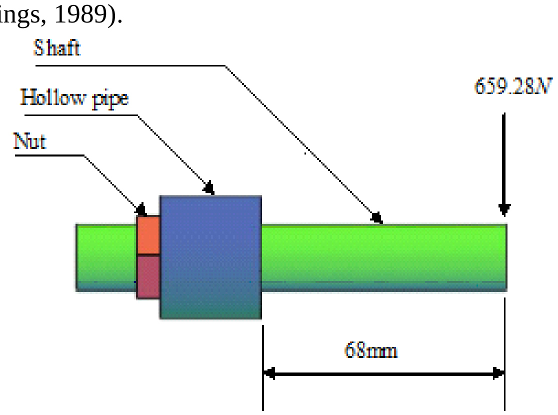


Fig. 6. Diagram to aid the design of the rear axle.

Moment is given as; force×perpendicular distance
From figure 5,
$M = 659.28 \times 0.068 = 44.83Nm$
From equation 3,

$$\delta = \frac{M}{Z};\ Z = \frac{I}{y};\ Z = \frac{\pi d^3}{32}$$

$$Z = \frac{\pi(0.0058)^3}{32} = 1.92 \times 10^{-8}$$

$$\delta = \frac{M}{Z} = \frac{44.83}{1.92 \times 10^{-8}} = 2.79MPa$$

This further confirms that the design is safe since the bending stress is low.

THE FRONT WHEELS

Large 60mm diameter non-marring front wheels were used to provide an increased mobility to roll over rougher surfaces.

THE PUSH CRANKS

The push cranks, not push rims, were tucked in tight and in line with the user’s shoulders. In conventional configurations the wheelchair user must reach outward, back, and push forward and down placing a good deal of strain on shoulders. The cranks used to propel the chair will offer a significantly more shoulder friendly motion than the bizarre shoulder gyrations used in conventional rim pushing. The push cranks will be made of about 20mm diameter and 750mm in length mild steel pipe. It will be attached to the existing inbuilt sprocket of the rear wheel of mountain bike through a system of six bolts and nuts to serve as an interlocked gear (Fig.7).

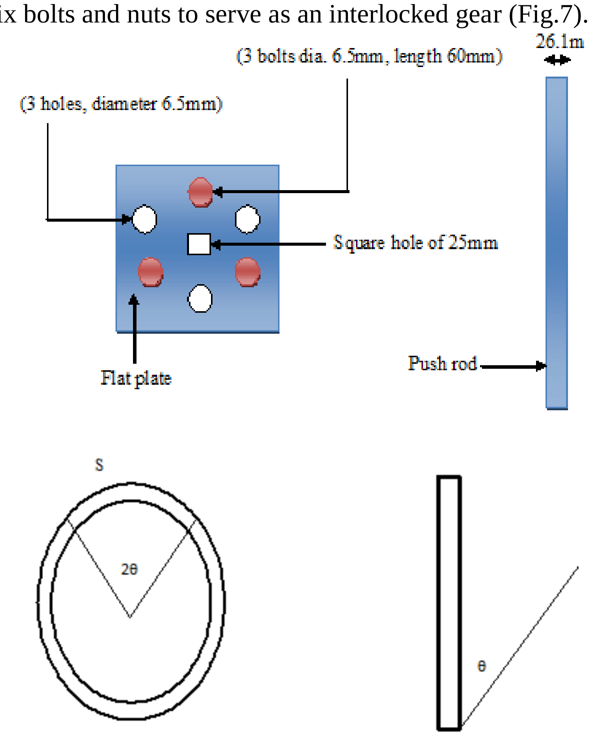


Fig. 7. The wheel and the push rod

B. Theoretical and Practical Speed of the Wheelchair

THEORETICAL SPEED OF THE WHEELCHAIR

The angle covered by the push crank is equivalent to the angle turned by the wheel. I assumed the forward and the backward movement of the push crank to be in simple harmonic motion and the length of the rod to be equal to the radius of the wheel.

The frequency of the push crank is given as:

$$f = \frac{1}{2\pi}\sqrt{\frac{mgd}{I}} \qquad (6)$$

Sterbheim and Kane (1986)

Where;

M = mass of the push crank; D = distance from one end of the push crank the center of gravity; I = moment of inertia of the hollow pipe; and G = gravitational force.

The mass of the push crank was calculated using equation (7).

$$density\ (\rho) = \frac{mass\ (kg)}{volume\ (m^3)} \qquad (7)$$

The density of steel is equal to 7820kg/m^3

$$mass = density \times \left(\frac{\pi d^2}{4} - \frac{\pi d_i^2}{4}\right) \times length\ of\ the\ rod$$

D being the outer diameter of the pipe and $D_i$is the inner diameter of the pipe

Therefore,

$$mass = 0.101kg$$

The moment of inertia I is given as

$$I = mR^2 \qquad (8)$$

Where; M = mass of the rod; and R = radius of the rod

$\therefore \quad I = 1.733 \times 10^{-5}$ and

$$\therefore \quad f = \frac{1}{2\pi}\sqrt{\frac{0.101 \times 9.81 \times 0.16}{1.733 \times 10^{-5}}} = 0.1096Hz$$

The period T is time taken to make a complete revolution or a cycle, since the push crank only travelled 60^0 of the revolution; it means that the time taken to cover this distance is 1/6th of the period T. That is 1/6T

$$t = \frac{1}{6T} = \frac{1}{6f} = \frac{1}{6 \times 0.1096} = 1.52s$$

Distance travelled per forward stroke is estimated from Fig.6, the length of the arc (s) corresponds to the linear distance travelled.

$$\theta = \frac{s}{r} \qquad (9)$$

Where; θ = Radian measure; s = Length of arc in linear unit; and r = Length of radius or the circle.

$$\therefore \quad s = r\theta = 0.32 \times \frac{2\pi}{360} \times 60 = 0.335m$$

The Speed therefore $= \frac{s}{t} = \frac{0.335}{1.52} = 0.22m/s$

PRACTICAL SPEED OF THE WHEELCHAIR/PERFORMANCE EVALUATION

The practical speed was estimated using a stop watch to measure the time it takes to propel the wheelchair over a distance of 10m at a normal operating condition. This was repeated for five times and the average time was then determined.

TABLE I
TIME TAKEN TO COVER DISTANCE OF 10M

S/N	1	2	3	4	5
Time(s)	23.08	23.02	22.24	22.97	22.83

$$Average\ time = 22.828s$$

Thus, the speed is given as $= \frac{10}{22.828} = 0.44m/s$

The results from the evaluations carried out were satisfactory.

IV. COST OF PRODUCTION

Cost accounting is simply the collection of the cost of individual components (cost of material, manufacturing, cost of labor, energy etc.) in order to determine the overall total cost of the product.

Cost accounting is very important in any engineering design, because it determines the selling price of the final product and helps the designer or manufacturer to know the breakeven price. The cost accounting for this project is outlined in table 1 and 2. And the total cost of production including the other variable cost (vis-a-viz: transportation and miscellaneous)amounted to $40, thus making the cost of production of the wheel chair to be $182.5 (US dollar).

TABLE II
NON-MACHINING AND MACHINING JOB COSTING

Job	Time Spent(hr)	Labour Cost/hr($)	Total Cost($)
Bending	2	6	12
Wielding	5	2	10
Painting	8	2	16
Machining/ drilling	0.5	8	4
Total			40

TABLE III
BOUGHT OUT COMPONENTS AND PARTS COSTING

Name	Specifications	Quantity	Unit Price ($)	Total Price ($)
Rear wheels	620mm	2	20	40
Front wheels	125mm diameter	2	6	12
Brakes	Caliper brakes	2	2	4
Upholstery	2$^1/_2$inch tick	1	25	25
Bolts and Nuts	Size 17 (155mm) long	5	0.5	2.5
Bolts and Nuts	Size 14 fine thread	2	0.5	1
Spring washer	Size 14	15	0.1	1
Nuts	Size 19	12	0.1	1
Sprockets	Size 20 – 22 feet	4	1.5	6
Pipe	3$^1/_4$inch 18ft long	2	5	10
Total				102.5

V. CONCLUSION

This design shows that through push crank control, an

effective self propelling off-road wheelchair can be developed. This is an indication that the challenges encountered from the usage of the conventional wheel chairs have been solved. Therefore putting this new development to stand in better position to assist the paraplegics in their mobility.The assembled wheelchair dimensions may differ a bit from those gotten from the design analysis. This may be due to the average manufacturing processes employed and the imperfection of the tools and materials available. The performance evaluation however shows that with more precision in fabrication, the equipment will function at a maximum efficiency.

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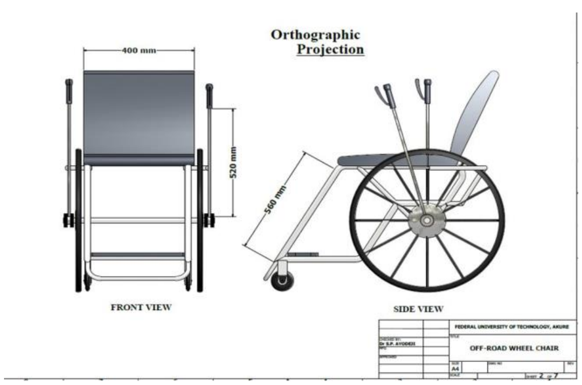
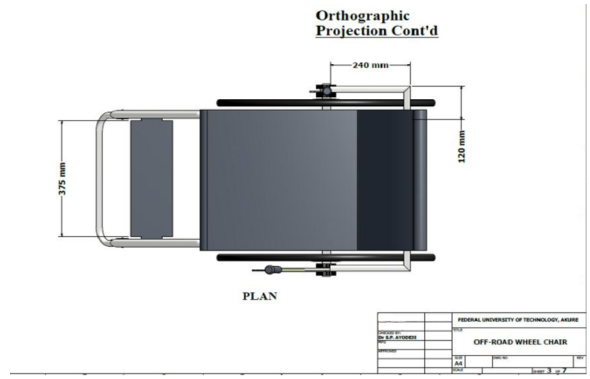
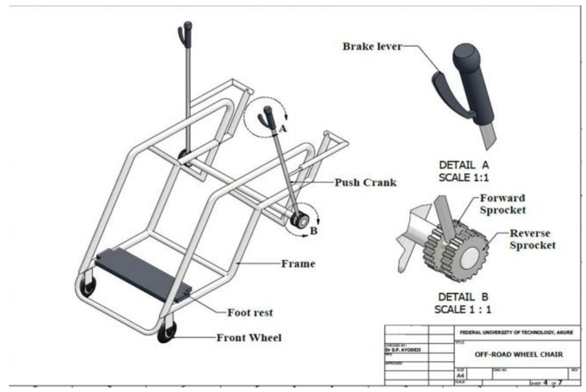
APPENDIX







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