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Design and Analysis of Washing Device for Disabled Persons

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Abstract

To help arm-disabled persons for washing, an assistive face-washing device was developed. The crank-link and flat putter-cam mechanisms were used to create hands movement for face washing by synthesis the flip and rotation movements during the washing process. The structure and water circuit of the device were designed in detail. Later, the three-dimensional model was constructed and the assembly and simulation as follow proved the feasibility of the design.

Keywords*: disability, face-washing device (FWD), design, simulation*

1. Introduction

According to the Second National Disabled census in 2006, the total number of all types of people with disabilities to 82.96 million, 6.34% percentage of the proportion of the country's population is people with disabilities, of which 24.12 million with physical disabilities, accounting for 29.07% of the total number of people with disabilities. In recent years, the snow disaster, Wenchuan earthquake and other disasters have caused a sharp increase in the number of persons with disabilities [1].

In recent years, natural disasters caused by the increase in the number of people with disabilities, in response to the appeal of the country, aimed at the people with disabilities in arm who temporarily lost the ability and the problem in washing face, so a assistive face-washing device was designed in this article [2, 3].

2. Functions

The assistive face-washing device was designed for people with disabilities in arm or the arm temporarily lost the ability to act. the device can help the arm-disabled people to wash, which constructed by cam-linkage to simulate the normal people's face-washing. The schematic diagram is shown in Figure 1.

The movement of the "hand" is synthesized by the two movements: the movement 1 is a horizontal reciprocating movement, constituted by the electrical box 12, the crank 1, link 2, the horizontal bar 3 and the upright bar 4 Upright bar and horizontal bar is settled connection.

Power transmits by the motor after reducer to drive the rotation of the crank 1, the left end of link 2 rotate with the crank, and the right end is connected with the horizontal bar 3. It can only do horizontal movement. Thus, circular movement of the crank is converted to the horizontal reciprocating motion of the horizontal bar. The horizontal bar 3 is connected with the upright bar 4, and the upright bar is connected at the end of the "hand". The "hand" in a horizontal reciprocating motion is driven by the reciprocation of the horizontal bar.

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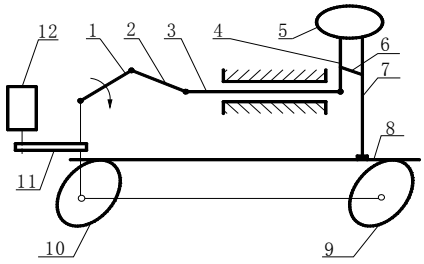


1 - crank ,2 - link ,3 - horizontal bar, 4-upright bar, 5 – hand, 6 - connecting rod, 7 - vertical bar, 8 - horizontal plate, 9 - cam1,10 - cam 2, 11 - belt, 12 –electromotor box

Figure 1. The Schematic Principle of Face-washing by Hand Movements

The movement 2 is the "hand" 's motion of turning, consists of the electromotor box, the belt 11, the cam 9, the cam 10, the horizontal plate 8, vertical bar 7 and the connecting rod 6, the electromotor drives the cam and make it turned, the horizontal plate by the gravity always contact with the cam 9 and cam 10's cylindrical surface. The rotation of the cam makes the horizontal plate up and down. Horizontal bar and vertical bar are always in contact.

Therefore, the vertical movement of the horizontal plate is driven by the vertical movement of the vertical bar. The vertical movement of the vertical rod resulted in the deformation of the parallelogram by the vertical rod, the connecting rod, the upright bar and hand, thereby forming the turning motion of the "hand".

The turning motion and the horizontal motion of "hand" help disability washing face. To make the disabled face-washing safety, comfort and convenience, considering all various situations of the disabled in arm, the device includes the functions of regulating the flow and the temperature of water. Those are controlled by the feet, safely and easily. The device can quickly dry the face with towel after washing. To alleviate the fatigue for stooping when they are washing, a freely movable and adjustable seat is designed. In addition, the supporting legs are also designed to deal with the vibration problems in using and moving, which can move freely and lock. To save water, a small water storage is designed to recycling of water.

3. Structural Design

3.1. Structure of the Simulated Hand

1) The size of the simulated hand is on the basis of adult hand, which is about 170mm length and 100 ~ 120mm width. The shape also mimicked adult hand to expand the effective of wash area.

2) A water pipe links the end of the simulated hand to pass water. To achieve the comfort of washing, the underneath of the hands is hard and hollow plastic and the upper surface is the layer of cotton material with aperture which will wash face more clean and comfortable.

3) To realize the rolling-over movement of hand, it both sides own a revolute pair, connected with the pin.

3.2. Design of Cam Linkage

3.2.1. Horizontal Movement of the Structural Analysis

The "hand", the stem and the horizontal rod is settled connected, which can get from Figure 2(a). The structure can be simplified as a slider-crank mechanism, shown in Figure 2(b). To achieve the horizontal movement of the "hand", the size requirements are on the crank 1 and the link 2. A horizontal moving distance; the other is a smooth rotation of the connecting rod and the horizontal bar [4-7].

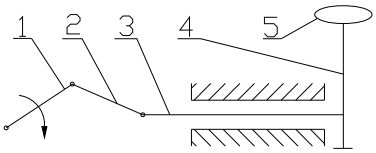
After Actually survey, the hand traveled distance when washing is H = 100mm and offset distance is e=10mm.

By the slider-crank mechanism length condition known:

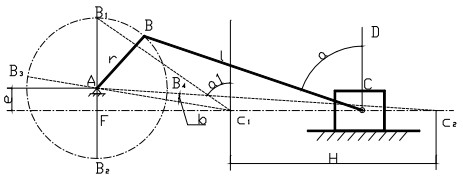
$$r \leq l \quad (1)$$

No dead point in the run-time, when the minimum transmission angle $a_{\min} = a_1 \neq 0$. Known by the relationship of triangular angle:

$$r + e < l \quad (2)$$



1 – crank, 2 – link, 3 - horizontal bar, 4-upright bar, 5 – hand



(a) structure diagram of horizontal movement (b) slider-crank mechanism analysis chart

Figure 2. Structural Analysis of Horizontal Movement

Figure 2(b), according to the Pythagorean Theorem,

$$H^2 = \left[(r+l)^2 - e^2\right] - \left[(l-r)^2 - e^2\right] \quad (3)$$

Let H, e into (3), r *l =2500.

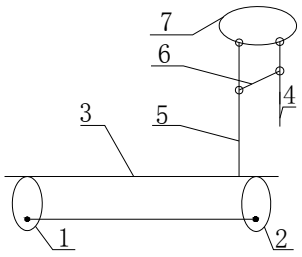
r= 40mm, l= 62.5 mm. And the results satisfy the inequality (1) (2) feasible.

For the imbalance angle b= $\angle C_1AC_2 \neq 0$(see Figure 2b), the mechanism is quick-return. Reduce the time of the return of the "hand", improve the efficiency.

Considering the size of the actual assistive face-washing device, the horizontal bar and the upright bar are 350mm and 400mm.

3.2.2. Flip Motion Analysis

The Flip motion of the hand is formed by the vertical movement of the vertical rod 5 and the horizontal plate 3 (see Figure 3). The horizontal plate movement is owing to the rotation of the cam 1, 2. Thus, the angle of hand flip motion is related to the shape and dimensions of the cam.



1 - cam 2, 2 - cams 1, 3 - horizontal plate, 4 -upright bar, 5 - vertical rod, 6 - connecting rod,7 – hand

Figure 3. Structure Diagram of Flip Motion

While width of hand is 110mm and connection point spacing is 90mm which known from the practice, the hand turning angle is about 30 degrees. Horizontal plate rising height is H = 90 * sin30 = 45mm.

The movement type belongs to flat-bottomed putting cam mechanism [3]. As shown in Figure 4.

Cam phase for rise.
Where:

$$\delta_{01} = 120° = 2\pi/3$$
$$s = H\left[1 - \cos\left(\pi\delta/\delta_{01}\right)\right]/2 \quad 0° \le \delta \le 120°$$

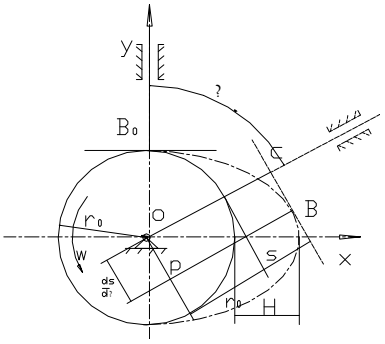


Figure 4. Analysis Chart of Flat-bottomed Putting Cam Mechanism

Hold phase of s remains unchanged.
Cam phase for return.
Where:

$$\delta_{02} = 120° = 2\pi/3$$
$$s = H\left[1 + \cos\left(\pi\delta/\delta_{02}\right)\right]/2 \quad 0° \le \delta \le 120°$$

Calculating the position of the various points, shown in Table 1.

Table 1. The Calculates Position of the Parious Points

Total angle	displacement/mm	Total angle	displacement/mm
0˚	0	240˚	45
60˚	22.5	300˚	22.5
120˚	45	360˚	0
180˚	45	0˚	0

Considering the prime circle radius formula:

$$r_0 \ge \sqrt{\left[\left(ds/d\delta - e\right)/\tan\left[\alpha\right] - s\right]^2 + e^2} \tag{5}$$

Where e=0, $\left[ds/d\delta\right]_{\min} = 0$ so $r_0 \ge 0$ mm, $r_0 = 50 \ge 0$ mm.

The pressure angle α of the cam mechanism is a constant value. The cam 12 contour curve is shown in Figure 5.

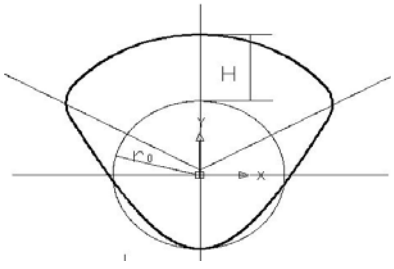


Figure 5. Cam Contour

Length of putter in flat-face cam mechanisms is:

$$l = 2\left|ds / d\delta\right|_{\max} + (5 \sim 7)_{mm} \quad (6)$$

$$l \approx 200\,\text{mm}$$

To ensure the putter is always in contact with the cam, $l \geq 2(r_0 + H) = 190$. let $l = 200$. Center distance of the two cams is $d = 600$. Then the length of the horizontal bar is $L = l + d = 800mm$.

Considering the contact of the horizontal plate and the cam rely on the self-gravity of the horizontal plate, the horizontal plate to use stainless steel plate, let sheet thickness of 12mm. With the synchronous rotation of Cam 1, 2, the transmission between the cam 1 and cam 2 driven by synchronous belt.

3.3. Motor Selection

The assistive face-wash device belongs to household appliances, and the power is household AC electromotor.

3.3.1. Speed of Motor

Considering human's washing speed, the frequency of assistive face-wash device is 60/min. From Figure 1, the frequency is equal to the crank speed n_w=60r/min. If the selected motor rated speed 1400r/min and full load speed n_m= 1350r/min, the total transmission ratio i = $n_m \setminus n_w$ = 1350 \ 60 = 22.5. The motor needs a two-stage gear reducer. And the output shaft of Reducer to the crank is driven by the belt, then the pulley radius ratio is 1:2 and the transmission ratio is i_b=2.the total transmission ratio of two-stage gear reducer is $i_r = n_m / i_b$ =11.25.

3.3.2. The Power Range of Motor

The assistive face-wash device work by the resistance of friction between the simulated hand and face and also among the various components within the friction. The frictional resistance is changed by the work time and the lubrication state changes. suppose that the maximum pressure applied to the simulated hands is 300N and the friction coefficient between wet towel and the face skin is about 0.6, then the maximum friction is $f_{\max}$ = 180N. In Figure 1, there is only horizontal motion and the friction is f in the flipping wash process. Set simulated hand horizontal velocity is v and ignore the frictional resistance among the mechanical parts, then the desired power is p_w = fv [4].

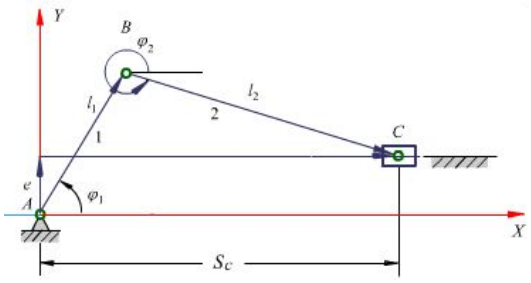


Figure 6. Analysis Chart of Slider-crank Mechanism Motion

As shown in Figure 6, $\vec{l_1} + \vec{l_2} = \vec{e} + \vec{s_c}$

Projected the closed vector equation to the axis:

$$\left.\begin{array}{l} l_1 \cos\varphi_1 + l_2 \cos\varphi_2 = s_c \\ l_1 \sin\varphi_1 + l_2 \sin\varphi_2 = e \end{array}\right\}$$

Eliminate φ_2, then:

$$s_c = l_1 \cos\varphi_1 + M\sqrt{l_2^2 - e^2 - l_1^2 \sin^2\varphi_1 + 2el_1 \sin\varphi_1} \quad (7)$$

set *M* = 1;

Recall that: $l_1 = r =$ 40mm, $l_2 = l =$ 62.5mm, e=10mm, $\omega = \dot{\varphi} = 2\pi rad/s$

From the equation (7), it follows that:

$$v = -8\pi \times 10^{-2} \sin\phi_1 + \frac{8\pi \times 10^{-4} \cos\phi_1 - 3.2\pi \times 10^{-3} \sin\phi_1 \cos\phi_1}{\sqrt{3.806 \times 10^{-3} - 1.6 \times 10^{-3} \sin^2\phi_1 + 8 \times 10^{-4} \sin\phi_1}}$$

There is a cycle speed - angle chart using MATLAB, as follows in Figure 7. So when φ_1 =1.67π , the maximum speed is $v_{\max}$ = 0.35m/s.

Maximum power $p_{w\max} = f_{\max} v_{\max}$ =63w.

Motor power $p_d = p_w / \eta$.

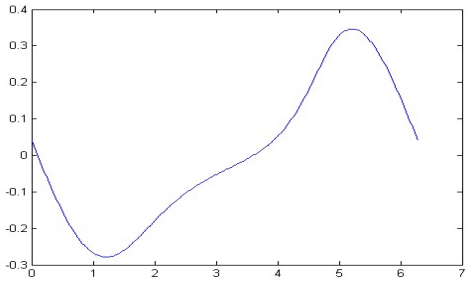


Figure 7. Speed-angle Chart

So when φ_1 =1.67π , the maximum speed is $v_{\max}$ = 0.35m/s.

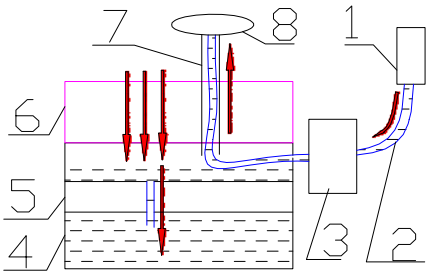
Maximum power $p_{w\max} = f_{\max} v_{\max}$ =63w.

Motor power $p_d = p_w / \eta$.

η is the total efficiency of the transmission apparatus and η = 0.9 * 0.9 = 0.81. So the critical power is $p_{d\max} = p_{w\max} / \eta$ =77.7w ≈ 78w.

And the minimum critical power is frictionless ideal no-load state, so $p_{d\min} = p_{w\min}$ =0.

3.4. Water Circuit



1 - Water faucet, 2 - water pipe, 3 – thermostat, 4 – reservoir, 5 – box, 6 – housing, 7 – upright bar, 8 – hands

Figure 8. Water Circuit

As shown in Figure 8, the pipe 2 can be connected to the tap 1 directly, and the flow is directly control by the faucet. The water flows go through the thermostat 3, which can control the temperature of the water. Water outflow from the thermostat by two soft leather tube water introduced from the small hole in the gray box. The upright bar 7 is hollow and two of the same soft leather pipe in the upright bar introduces the water toward the hand 8. After washing the face, water floating down the shell through the laces to the box 5 and last into a small reservoir 4 which can be recycled.

3.5. Apparatus for Dry Face

To solve the problems of arms disabled dry face quickly, retractable apparatus designed which can wipe and dry the face quickly and comfortably after washing. The surface is compose of cotton material with good ventilation absorbent and there is air heater and a small dryer inside. Butterfly heart-shaped appearance is not only convenient, but also beautiful and practical. See the results shown in Figure 9.

3.6. Seat Design

For the arms disabled washed more comfortably and to avoid the fatigue caused by stoop, the barber's seat is used which has a spherical ball feet, can do 360° rotational movement and be able to move up and down used a threaded rod.

3.7. Supporting Legs

To freely move, the support legs must be able to do 360° rotation movement, and can be locked in combination with each other. So a unidirectional roller type of supporting leg is designed, which can easily move and lowly vibrate when working by equipped with a spring inside.

3.7.1. Modeling and Simulation Based on Pro/E

The face-wash device is modeled in Pro / E, as follows in Figure 9.

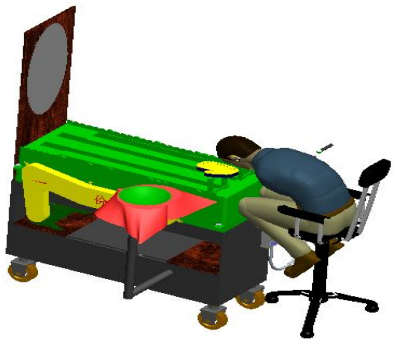


Figure 9. Assistive Face-wash Devices

In the Pro / E, to create the connection, add in servo motor, create and perform analysis and playback. Simulation during exercise in Figure 10.

As shown in Figure 10, the assistive face-wash device achieves the wash function by the tow processes.

From Figure a to d, hands can move from front to back and flip to achieved the process of rubbing the face; Figure e and f for the return movement and hands can flip to the horizontal, also the hands leave face and rapid return. And so forth, to complete the wash. Each cam and link motion is coherent, smooth and meet the design requirements of the sport.

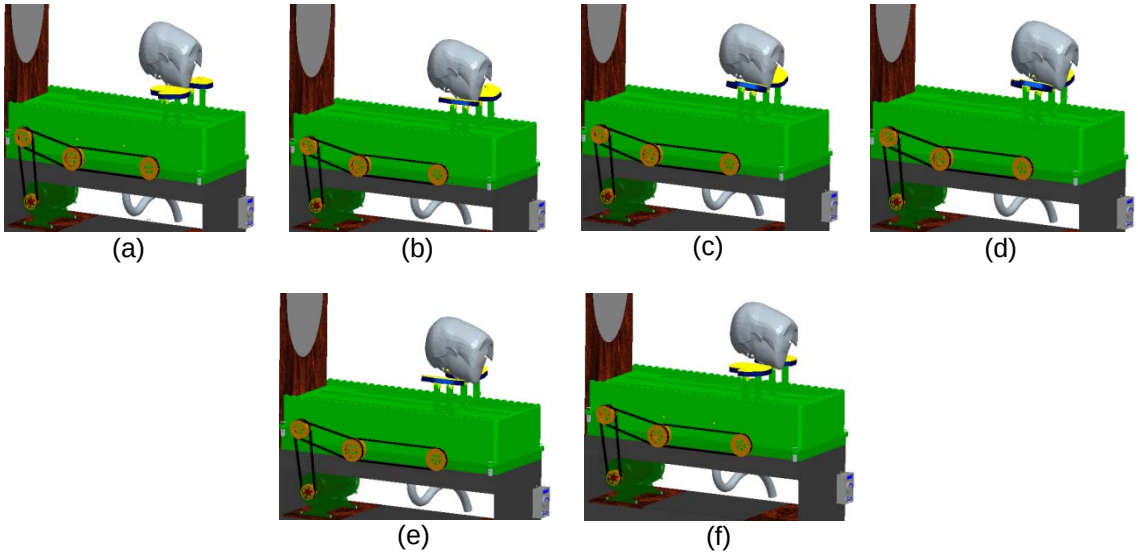


Figure 10. Assistive Wash Apparatus Process Diagram

4. Conclusion

With the improvement in the level of social progress and civilization, how to use high-tech means to enhance people with disabilities living space will be more and more attention. The new face-wash device is designed to help the arm disabled. And the function principle and the design process is introduced and fully consider the wash movement and structure of the force. Last, the 3D mode and motion analysis to confirmed the possible to solve the arm disabled life problems with the device, which will reduce the cumbersome nature of taking care of persons with disabilities.

Acknowledgements

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