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Special sliding door with storable handrail to support senior and handicapped persons to walk by themselves

K Saitou[1,4], N-A Noda[2], Y Sano[2], Y Takase[2], K Murai[2], Z F Wang[2], S Q Li[2], X Liu[2], H Tanaka[2] and Y Kubo[3]

[1]Yahata Rolling Mechanical Engineering Department, Engineering Division, Mechanical Engineering Unit, Nippon Steel & Sumikin Texeng. Co. Ltd, Kukioka 2142-1 Maeda Yahata higashi-Ku, Kitakyushu-Shi, Fukuoka, Japan
[2]Mechanical Engineering Department, Kyushu Institute of Technology, Sensui-Cho 1-1 Tobata-Ku, Kitakyushu-Shi, Fukuoka, Japan
[3]Kei products Co. Ltd, Wakahuji-Cho1-26-203 Kokurakita-Ku, Kitakyushu-Shi, Fukuoka, Japan

E-mail: saitou.kinjirou.ks@tex.nssmc.com

Abstract. In this paper, special sliding door is designed in order to support senior and handicapped persons to walk by themselves in hospitals and nursing facilities. This semi-automatic lifting equipment is utilized for the storable handrail to make sure the bad health persons are able to open the door by using a weak force. In this study, to design the equipment of the handrail, the theoretical formula of opening force is derived. Then the simulation is performed by varying geometrical conditions. The simulation results are compared with the experiment results.

1. Introduction

For elderly people needing nursing care, handrails are often installed all over the entire side of the corridor and walking places in their homes and hospitals so that they can grab the handrail and walk by themselves. Keep walking is very important for elderly people to maintain their walking ability as well as to restore their walking function [1-3]. However, Japanese hospitals and homes usually have a lot of sliding doors, which prevent installing the standard handrail. In other words, since Japanese homes and hospitals have a lot of no handrail space at sliding doors, elderly people cannot walk by themselves by using handrail. From this point of view, in this research, we aim to develop a special sliding door with storable handrails [4,5] to support eldering people walking by themselves. Figure 1 shows the prototype special sliding door considered in this study. To obtain the most desirable handrail geometry, theoretical formula will be derived to estimate the opening force of the sliding door. Also experimental measurement will be performed for the prototype sliding door to confirm the validity of the theory.

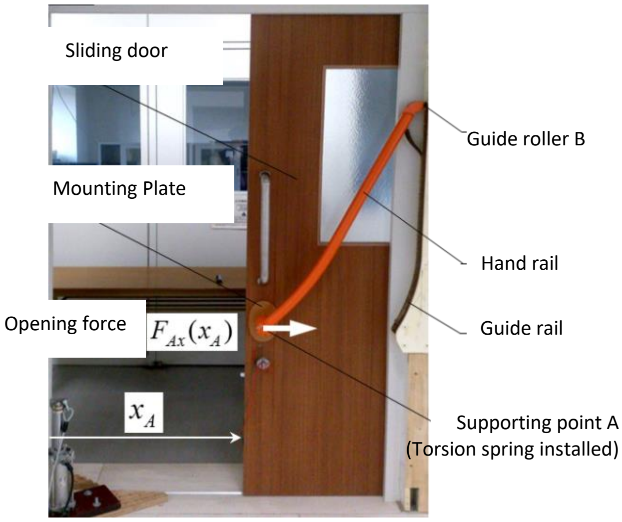

Figure 1. Prototype sliding door with storable handrail.

2. Structure of the sliding door

2.1. Structure of sliding door

Figure 1 shows the prototype handrail storable sliding door considered in this study. This special door consists of a sliding door, a storable handrail, a fulcrum handle, a rotating roller at the end of a storable handrail and a guide rail. The torsion spring is used to reduce the torque due to the handrail weight W for opening the door (see the moment M in figure 2). By using the torsion spring, the opening force can be reduced. The spring constant is chosen to reduce the opening force in the prototype handrail. When the sliding door is completely closed, the storable railing serves as a handrail to support elderly people walking. When the sliding door is being opened by someone, the storable handrail is rotating on the point A in anticlockwise direction and the guide roller B is going upward along the guide rail. When the door is being closed, the storable handrail is rotating on the point A in clockwise direction and the guide roller B is going downward along the guide rail due to the own weight of the handrail.

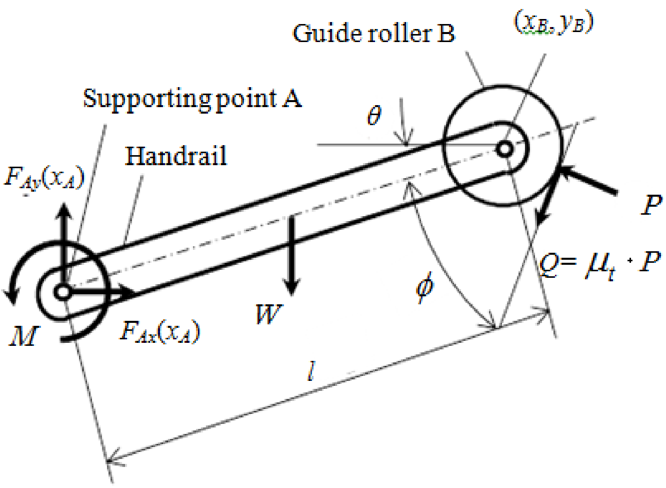

Figure 2. Equilibrium of force with a torsion spring.

2.2. Notations

The following notations will be used in this paper.

$F_{Ax}(x_A)$: Opening force applied at point A in figure 2. The target value $F_{Ax}(x_A)$=19.6 N

$F_{Ay}(x_A)$: Reaction force applied to the handrail at point A $(x_A, 0)$ in the y-direction in figure 2

$(x_A, y_A) = (x_A, 0)$: Coordinate of the supporting point A in figure 3, x_A = Opening distance of sliding door

(x_B, y_B) : Coordinate of point B in figure 3, point B = Center of guide roller

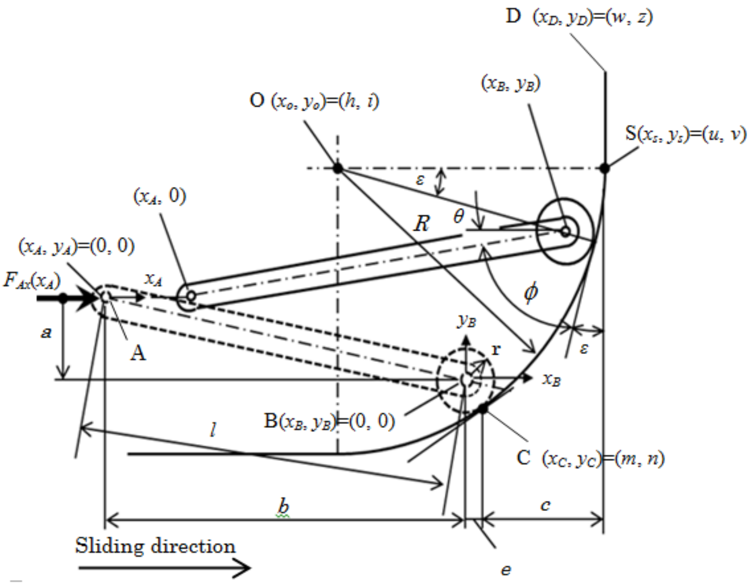

Figure 3. Model of storable handrail.

(x_0, y_0) : Coordinate of point O in figure 3, point O= Center of arc portion of guide rail

Q : $Q = \mu_t \cdot P$, Running resistance (see figure 2)

P : Reaction force to the handrail from the guide rail at point B in figure 2

R : Rolling surface radius of guide rail stand in figure 3 (R = 478 mm for prototype)

θ : Angle between the storable handrail and the horizontal line (see figure 3)

ϕ : Handrail angle between the tangential direction of the guiderail at B and hand rail (see figure 3)

ε : Guide rail angle between the tangential direction of the guiderail and vertical direction (see figure 3)

W : Weight of handrail including guide roller in figure 2 (W = 13.7 N for prototype steel handrail)

M : Moment due to torsion spring in figure 2 ($M = k(0.5\pi - \theta)$)

k : Spring constant (k =2395N・mm/rad)

μ_t : Friction coefficient of bearing 0.03 + friction coefficient of rotating roller 0.05 in figure 2 (μ_t =0.03+0.005=0.035) [6]

a : a= $y_b - y_a$, AB in the y-direction in figure 3 (a = 22.6 mm for prototype)

b : Horizontal difference, b= x_A - x_B , between point A – point B in figure 3 (b = 910.3 mm for prototype)

c : Distance from the guide roller contact point to the rail vertical point in figure 3 (c =58.2 mm for prototype)

r	: Radius of the guide roller B in figure 3 (r =17.5 mm for prototype)
e	: The distance in the x direction from the horizontal distance between center point of the guide roller B and the contact point of the roller and the rail in figure 3
l	: Length of storable handrail rod in figure 3 (l =910.3 mm for prototype)
C	: Contact point of the roller in figure 3
S	: End point of the curved portion of the guide rail in figure 3
D	: Guide rail end in figure 3

3. Analysis of sliding door opening force

3.1. Equilibrium of the handrail to obtain the opening force

Figure 3 shows the handrail model to be considered. Assume the torsion spring is not installed to the rotary fulcrum shaft. Figure 2 shows the free body diagram for the handrail where a torsion spring is installed to the rotation support shaft. Equations (1)-(3) are derived from the equilibrium in figure 2.

$$F_{Ax}(x_A) = Q\cos(\theta+\phi) + P\sin(\theta+\phi) \tag{1}$$

$$F_{Ay}(x_A) + P\cos(\theta+\phi) = W + Q\sin(\theta+\phi) \tag{2}$$

$$M + lP\cos\phi = \frac{1}{2}lW\cos\theta + lQ\sin\phi \tag{3}$$

Therefore, the following equations can be obtained [7].

$$F_{Ax}(x_A) = \mu_t P\cos(\theta+\phi) + P\sin(\theta+\phi) \tag{4}$$

$$F_{Ay}(x_A) = W + \mu_t P\sin(\theta+\phi) - P\cos(\theta+\phi) \tag{5}$$

In figures 2 and 3, two coordinates are used. One has the origin of the center coordinate (x_A, y_A) = (0, 0) at the rotation fulcrum A. The other has the origin (x_B, y_B) = (0, 0) at the center of the radius of curvature R. It is taken as reference coordinates.

Next, the central coordinates (x_B, y_B) of the guide roller B with respect to the moving amount x_A of the rotation fulcrum A, and θ and ϕ determined from the curvature radius R and its center point O (h, i) are obtained by the following equations (figure 3).

$$\theta = \tan^{-1}\frac{y_B - a}{\sqrt{l^2 - (y_B - a)^2}} \tag{6}$$

$$\phi = 90° - (\theta + \varepsilon) \tag{7}$$

$$\varepsilon = \sin^{-1}\frac{i - y_B}{R - r} \tag{8}$$

From equations (1) to (8), $F_{Ax}(x_A)$ can be obtained as equations (4), (5). Note that the effect of inertial force on opening force $F_{Ax}(x_A)$ is small enough and can be negligible.

3.2. Experimental measurement of the opening force

Figure 4 shows the measured opening force for the prototype sliding door as the dashed. In figure 4, the results of the equation (4) are also indicated as the solid lines by varying the curvature radius R of the guide rail. The experimentally obtained opening force was measured by using a spring scale when the door is opening at a constant speed of 15 mm/s. The theoretical value was obtained for five kinds of curvature radii in the range of R = 200 mm to 600 mm. The opening force F_{Ax} (x_A) gradually increases with increasing x_A and taking a peak value at the vicinity of x_A = 79 - 99 mm, and thereafter decreases suddenly. It is found that the maximum value of the opening force is generated when the handrail end B is at the end of curved position. The maximum value of the opening force increases with decreasing the radius of curvature R. The maximum load obtained theoretically when the radius of curvature R = 478 mm is $F_{Ax\max}$ = 19.5 N and the maximum load obtained experimentally $F^{Exp}_{Ax\max}$ = 22.4 N. Those difference 13% may be caused by the error of the analytical and experimental results. The experimental error may be caused by the fabrication and assembly errors of guide rails. The suitable opening force for elderly people can be estimated as $F_{Ax\max}$ =19.6 N. For the elderly people, it is dangerous if the opening force $F_{Ax}(x_A)$ is too small for this sliding door because this door is used as the handrail. In figure 4, this target load can be satisfied theoretically as shown the dashed line in figure 4. However, the experimentally measured opening force for the prototype door is larger than this target value by 2.8 N, which is 14% larger than the target value. Such load difference of 2.8 N can be reduced by improving the manufacturing proficiency for the storable handrail and by adjusting the torsion spring attached to the rotational fulcrum A. The load difference of 2.8 N corresponds to the torsion spring torque error about 400 N･mm. In other words, the target opening force can be realized by the design data shown in Section 2.2.

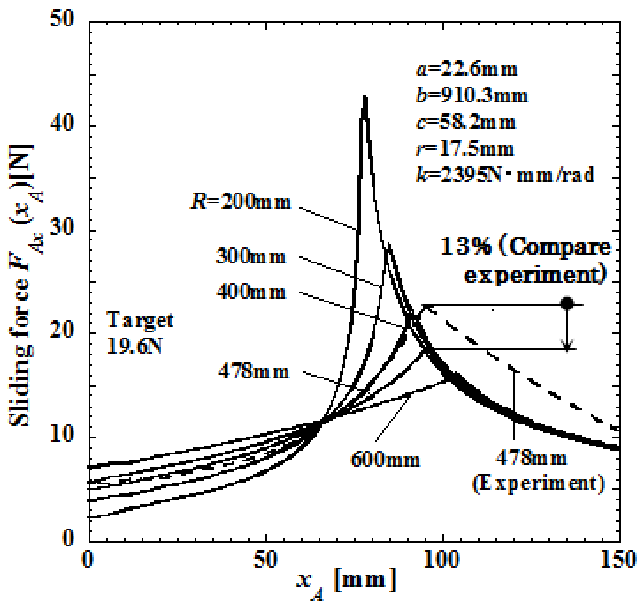

Figure 4. Sliding force F_{Ax} (x_A) calculated by theoretical.

3.3. Consideration of sliding door opening force behavior

In figure 4, there is a peek point where the opening force F_{Ax} (x_A) abruptly increases to the maximum value. It can be seen that this maximum value increases with decreasing the curvature radius R of the guide rail. Figure 4 shows the both results of F_{Ax} (x_A) obtained theoretically and experimentally. Figure 5 compares with increases F_{Ax} (x_A) and Handrail angle ϕ , and takes peak value.

It should be noted that the maximum value of F_{Ax} (x_A) appear at $x_A \cong$ 90mm and the maximum value ϕ also appears at $x_A \cong$ 87 mm.

Note that in figure 5 contact of Point S (x_S, y_S) =(u, v).

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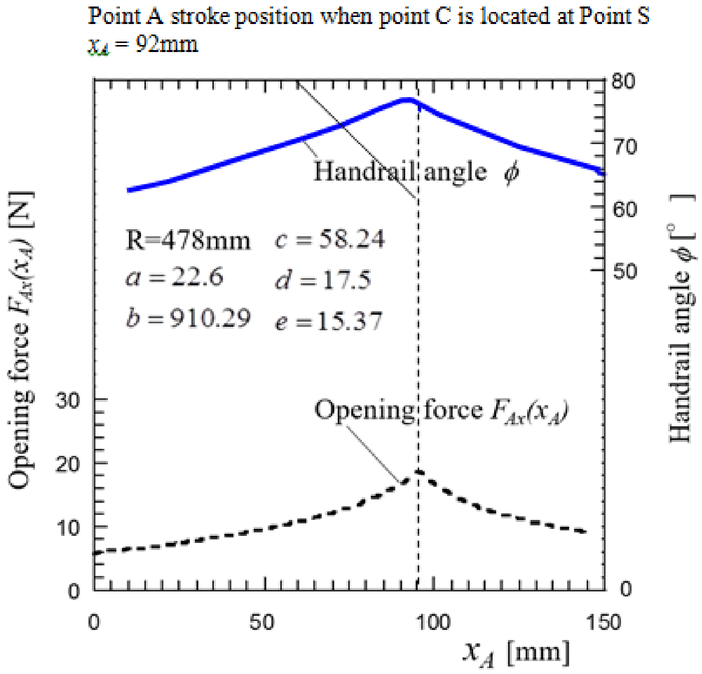

Figure 5. Comparison between the opening force $F_{Ax}(x_A)$ and the angle ϕ.

It should be noted that the position where the maximum opening force appears to the end Point S where the curved guide roller changes to the straight as shown in figure 3.

4. Conclusion

In this study, in the sliding doors with handrails, a theoretical formula for simulating the opening force was obtained, and the force to open the sliding door was analyzed using it.

- The maximum value of the sliding door opening force coincides with the actual measurement result within the error of 13% by using the simulation method of this study.
- By using a torsion spring for the rotation fulcrum A, by appropriately combining the height difference between the rotation fulcrum and the roller and the radius of curvature of the guide rail, the sliding door opening force can be designed to the target 19.6 N or less.

References

[1] Ministry of Health 2006 Research on health promotion effect of walking support program for community elderly people *Labor and Welfare Business report on Health Promotion, etc. for the Elderly* 29
[2] Kim H K, Yoshida H and Suzuki T 2001 *Jounal of Japan Geriatrics Society* **38** 805-11
[3] WHO Global Report on Falls Prevention in Older Age: WHO Library Cataloguing-in-Publication Data ISBN 978 92 4 156353 6 (NLM classification:WA 288) 20-1
[4] Kei・Products Co. Ltd, Handrail for sliding door, sliding door device, Sliding door device, Patent application 2010-102602, Public number 2011-231513
[5] Kei・Products Co. Ltd, Handrail for sliding door, sliding door device, Sliding door device, Patent application 2012-133492, Public number 2013-256808.
[6] Kakuta K 1992 *Machine Design Handbook* 3th Edi. p 652
[7] Andou T 1968 *JSME Mechanical Engineers' Handbook* Rolling friction 5th Edi. **3** p 34