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Research paper

A feasibility study of variable linkage mechanisms for adjustable table fans with selective rotation angles

Soo-Han Lee, Jeong-Eun Han, Do-Hun Kim, Sang-Hyun Kim*

Dept. of Mechanical Systems Engineering, Hansung University
116, Samseongyo-ro 16Gil, Seongbuk-gu, Seoul, 02876, South Korea
**Corresponding author E-mail: shkim@hansung.ac.kr*

Abstract

This paper addresses a relatively simple method that enables to adjust the rotation angle of the output linkage to fit desired situations using variable four-bar linkage mechanism. The selective rotational angle sections are determined by experiments and the appropriate lengths of linkage to fit each section are analytically calculated. Changes in the linkage length are implemented by the rotational motion using a grooved cylindrical cam. The presented variable linkage mechanism is applied to the commercial table fans, which is a representative product using a four-bar linkage system, to enhance its efficiency through the adjustment of rotation angles. Finally, the feasibility of the proposed variable linkage mechanism is verified through fabrication and measurement.

Keywords: *Cylindrical Cam, Four-Bar Linkage, Table Fans, Turning Angle, Variable Linkage Mechanism*

1. Introduction

The table fan is one of the most common electric appliances used in indoor spaces such as houses, offices and other business areas to provide a more comfortable atmosphere with air circulation during hot and humid summer days [1-4]. The functions of fans include wind speed adjustment, timer and left/right turns. Normally, the wind strength adjustment function divides wind strength into breeze, light and strong winds and the timer function enables the setting of fan operation time within a range of 0-8 hours. Therefore, the user can choose the wind strength and operating time selectively depending on the situations. However, the commercial fan only has binary stationary/rotating function and provides the wind in a limited space around it due to its oscillating mechanism. Also, the left/right turn function has only one turning section, meaning that the oscillating angle cannot be adjusted leading to cases whether the wind reaches areas where no wind is necessary, or vice versa.

Recently, the modified oscillating mechanism has been proposed to enhance the rotating range, which uses male and female connectors in the stand of a fan and enables a 360° rotating angle [5]. However, this attempt only provides one turning section and the user can not choose the selective turning angle levels like 30°, 90° or 180°, etc. Therefore, to enhance the efficiency of fans, a function that will enable the adjustment of the range of left/right turns according to situations is required.

All rotating mechanisms of fan currently available on the market are implemented by the four-bar linkage structure located in the turn driving unit. The four-bar linkage structure is a representative linkage structure and has been used in variety of industrial applications due to its simple structure, ease of manufacturing, and low cost [6-12]. It consists of four links connected with pin joints and allows diverse drives, depending on the methods of combined links and movement constraints. Because the path or form of movements cannot be easily changed as long as the length of linkage is fixed, the linkage length should be changed to adjust the turning range of linkage structures [13]. However, since the links are rigid bodies that cannot be adjusted in length, to selectively adjust the driving angle of the output linkage, the independent four-bar linkage mechanism should be redesigned and reinstalled, which is inconvenient. This is why the commercial table fan using four-bar linkage allows only one rotating range.

To solve the problem as such, attempts have been continuously made to control the turning angle by attaching a servo or a stepping motor to the turning unit without using the linkage structure [14-17]. However, the turning angle adjustment through the motor control has not been commercialized due to the expensive installation cost and the operation complexity [18-21].

In this study, a variable linkage structure that enables selective adjustment of output linkage movement is presented and applied to fans to enhance its efficiency through the adjustment of rotation angles. First, the number of turning angle sections are selected to efficiently divide the winds of the fan through experiments and the linkage lengths necessary for individual turning sections are calculated. In addition, a variable linkage mechanism is implemented using a cylindrical cam so that the linkage lengths can be selectively adjusted for stepwise sectional turnings and the validity of the linkage mechanism is verified through fabrication and experiments.

2. Theoretical background

2.1. Selective turning angles for fan efficiency

First, the necessary turning angle of fans is selected to apply the variable four-bar linkage mechanism to fans. Generally, a fan has only one turning section and cannot adjust the turning angle, so the wind could either not reach areas it needs to or reach areas it should not. Therefore, in this study, the efficiency of fans will be enhanced with the minimum shape modification and the division of the turning angle so that the turning section can be adjusted according to situations.
Figure 1 shows the flow of wind from a fan when it is stationary, in order to set the number of turning sections. If the fan does not turn and blows forward, the wind will cover a certain areas.

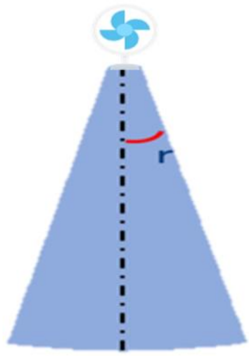
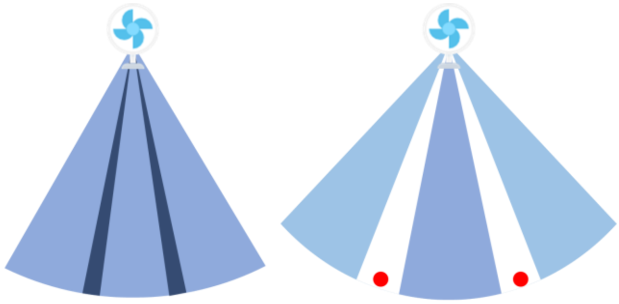


Fig. 1: Stationary wind direction angle

When the blowing angle to the central axis of the fan is assumed to be r, the angle of area where the wind covers is 2r, which is called the stationary wind direction angle. Although this value decreases as the wind strength increases, in this study, the smallest value is used so that the wind can reach wider areas than the area calculated using the stationary wind direction angle.
When the fan turns, the wind reaches the area covered by the turning angle of the fan plus the stationary wind direction angle. If the turning angle levels are set too small, the wind may overlap in every turning level. On the other hand, an excessive turning angle induces a certain area where the wind does not reach.

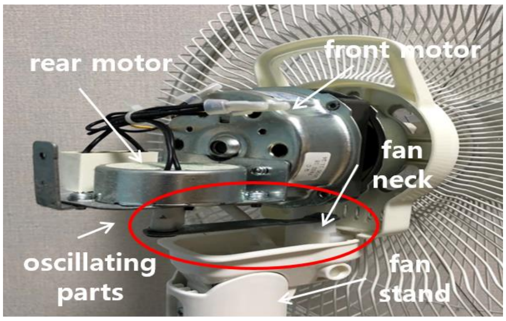


(a) Wind overlapping state (b) Excessively turning state
Fig. 2: Wind area according to the turning angle

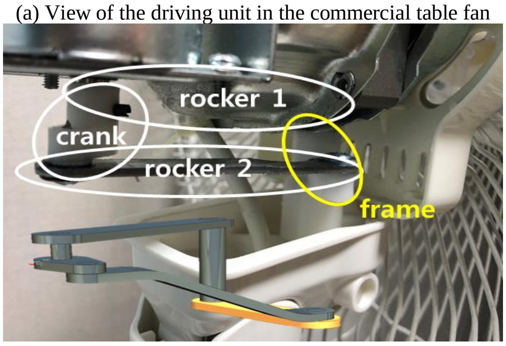
Therefore, in order to determine an effective turning angle, the number of levels of turning should be set so that the overlapping state where winds overlap and the excessively turning state as shown in figure 2 will not occur. The effective turning angle and the minimum number of turning level are determined by experiments.

2.2. Variable four-bar linkage mechanism for turning angle adjustment

Figure 3 (a) shows the driving unit of the commercial table fan, which includes the front and rear motor, the fan blades and neck, and the oscillating parts. The fan blades are mounted on the front motor shaft and can blow forward through the rotation motion. The rear motor is also connected to one component in the oscillating part. Due to the oscillating mechanism, the fan head turns from side to side, changes the direction of its air circulation and distributes air to a larger space. The fan can switch easily between a stationary and rotating mode with the use of a knob, which is placed on top of the front motor body. When the knob is pushed, it connects to the oscillating parts and the fan head can be turned. When the knob is pulled, it disconnects with the oscillating unit and the fan is stationary.
The oscillating parts are shown in figure 2(b) and consist of the following: The distance between the axis of the fan neck and the axis of the rear motor is a rocker 1, and the iron rod between the axis of the large motor in front and the axis of the small motor at the rear is a rocker 2, respectively. The rocker 2 is also mounted on the stand of fan and makes the fan oscillating. The part that connects two rockers with each other is a crank. Finally, the distance between parts protruding from the axis of the front motor and the fan neck is called a frame. Therefore, the driving unit is a double locker structure consisting of two rockers, one crank, and one frame. The lower image in figure 2 (b) shows a schematic diagram of the oscillating mechanism of the driving unit expressed as a four-bar linkage structure. Comparing with the real components in the figure 2 (b), the rocker 1 and the frame linkage do not actually exist and are virtually expressed for understanding.



(a) View of the driving unit in the commercial table fan



(b) Basic components in the oscillating parts

Fig. 3: Basic components of the driving unit and its oscillation mechanism

Figure 4 shows the oscillating mechanism of the maximum and minimum driving angles of the linkage when the fan turns [13]. The linkage consists of two lockers (D, E), a crank (C), and a frame (F). The driving of the rocker D determines the turning range of the fan. Therefore, the difference between the minimum turning angle (θ_1) and the maximum turning angle (θ_2) of the rocker D, that is, the maximum rocker driving angle (θ) becomes the turning angle of the fan.

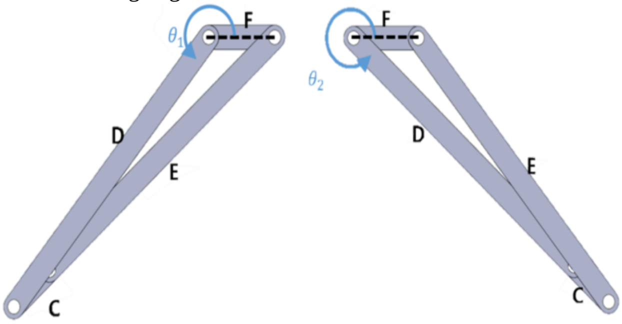


Fig. 4: Minimum (left) and maximum (right) turning angle of the rockers

The turning angle of the fan, that is, the maximum rocker driving angle (θ) can be obtained using equation (1).

$$\theta = \cos^{-1}\left(\frac{F^2 + D^2 - (E-C)^2}{2FD}\right) - \cos^{-1}\left(\frac{F^2 + D^2 - (E+C)^2}{2FD}\right) \quad (1)$$

However, as shown in equation (1), since all linkages of existing fans are rigid bodies with fixed lengths, an additional four-bar linkage should be designed for each driving angle for selective control of the turning range. This feature of four-bar linkages acts as a limitation leading to the low efficiency of machine driving. In addition, although methods of adjusting the turning by installing an electronic control device or adding a motor were used, the fan turning angle adjusting function has not been commercialized due to limitations such as increases in the cost of product design in the process of installing and controlling the motor, and inapplicability to existing products.

Therefore, in this study, a method is proposed that enables the adjustment of the turning angle by utilizing the conventional four-bar linkage. Figure 5 is a conceptual diagram of a variable four-bar linkage mechanism capable of adjusting the driving angle of the output linkage in a single linkage structure. The kinematic scheme of the conventional four-bar linkages mechanism is maintained, and the one linkage shape of four linkages can be changed to enable the selective mechanical driving and overcome the kinematic limitations of four-bar linkages.

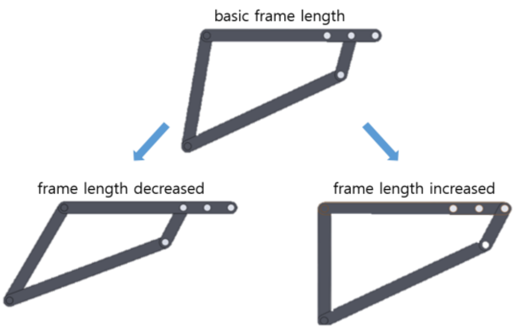


Fig. 5: Conceptual diagram of the variable linkage mechanism

While the fan turns, the frame is fixed to the front motor and the fan deck, so the equivalent frame length can be easily changed. However, because the remaining three linkages out of the four-bar linkage in a double locker structure move in turning operation and the movement of the modified linkage mechanism may cause the conflict in other parts of the driving unit, it is difficult and complicated to change the shape, Therefore, the shape of the frame will be changed to realize the variable linkage mechanism. Unlike the electronic mechanism, this mechanism minimizes the modification of the linkage configuration and can be applied to existing fans, so the additional product design cost can be saved.

The frame linkage length for adjusting the turning angle can be controlled by using the conventional motion converting devices such like the rack-and-pinion [22], the left-right motion of the guide rail [23], and the rotational motion of the cam [13]. This conventional device connects to one of the frame joints. Translation movement of the joint due to these motion control devices induces the change of frame length and can adjust the range of left/right turns of the fan according to situations.

3. Implementation of the variable four-bar linkage mechanism

3.1. Determination of the selective turning angles

First, to obtain the efficient turning angle levels, the stationary wind direction angle was obtained through experiments. A schematic diagram to experimentally determine the stationary wind direction angle is presented in figure 6, where d is the diameter of the fan head, y is the vertical distance from the fan, and the horizontal distance of x from the central axis of the fan means the wind spreading range, respectively. The ranges how much winds spread by distance were measured according to the wind speed and the wind blowing angle of r was calculated by using the relation of $r=\tan^{-1}((x-d/2)/y)$.

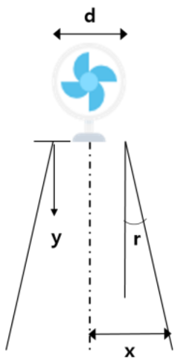


Fig. 6: Schematic diagram to measure the stationary wind direction angle

Table 1 shows the experiment result of the wind spreading range according to the wind speed by the vertical distance from the fan. Because winds blow straightforward at 0 to 1000mm range of the vertical distance, the wind spreading ranges were measured at the vertical distance from 1000mm to 5000mm with an interval of 500mm and transferred to the wind direction angles.

Table 1: Experiment result of the maximum wind spreading range by the vertical distance from the fan (unit: mm)

vertical distance	wind spreading range		
	Breeze	Light	Strong
1000	843	747	649
1500	1079	936	773
2000	1321	1110	1035
2500	1538	1288	1241
3000	1772	1475	1453
3500	1920	1620	1661
4000	2135	1780	1877
4500	2390	1862	1986
5000	2545	1920	2150

Figure 7 presents the determined wind blowing angles according to the wind speed by the vertical distance from the fan when the diameter of the fan head is 90cm. As shown in table 1, the wind blowing angle becomes small at high wind speed and closer to the fan. Through experiments, it could be seen that the minimum wind angle is 11.25° and the stationary wind direction angle 2r is 22.5°.

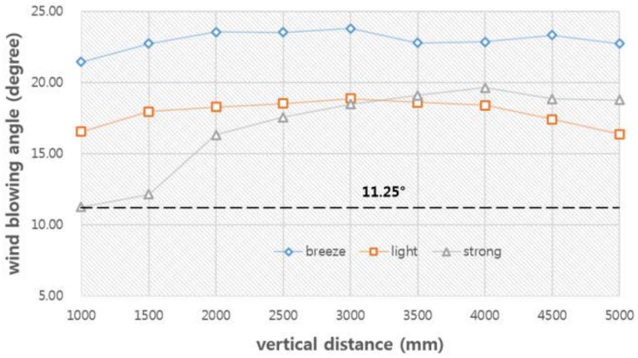


Fig. 7: Determined wind blowing angles by the vertical distance

Figure 8 shows the minimum turning angles indicated based on the central axis (center line) of the fan considering the efficient turning range of the fan.

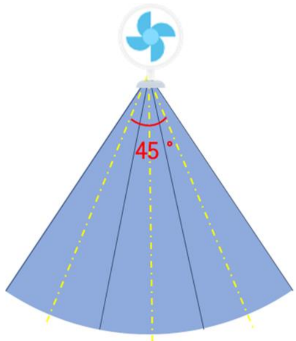


Fig. 8: Experiment result of minimum turning angle for the efficient turning range

Since the stationary wind direction angle is 22.5°, the minimum angle at which the winds do not overlap and the fan does not turn excessively becomes 45°. Therefore, the efficient turning angle of the fan can be divided into 4 levels as 45°, 90°, 135° and 180°, and the ranges where winds reach when the fan turns become 67.5°, 112.5°, 157.5°, and 202.5°, respectively.

However, since most the space is rectangular, the wind blowing range will be larger than the necessary range at the level of 180° turning angle. And the variable linkage structure also may collide with other parts in the driving unit of conventional fans when the fan turns up to 180°. Therefore, the level of 180° turning angle was excluded. In addition, when the level of turning angle is 135°, the wind reaches within the area with the angle of 157.5° and there exists the sections of 11.25° not reached by winds on both sides of the fan. However, since the proposed stationary wind direction angle of 22.5° is the smallest angle among the experiment result values, the average stationary wind direction angle is greater than 22.5° and the sections not reached by winds become smaller. Moreover, when people are exposed to winds in an area of 100m^2 as shown in figure 9, the space occupied by 11.25° is smaller than the space occupied by one adult and the person at the corner can also enjoy winds. Therefore, the minimum number of turning levels for efficiency becomes three and the angles are set to 45°, 90°, and 135°.

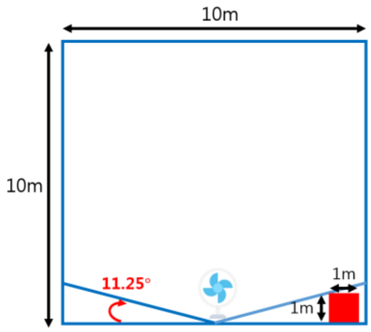


Fig. 9: Exposure of winds in an area of 100m^2

3.2. Control of the variable length of the frame

If the three levels of efficient turning angle determined through experiment are substituted into equation (1), the required frame lengths according to the angles can be obtained as 3.06cm, 1.63cm, and 1.24cm. Figure 10 expresses the required frame lengths according to the three levels of turning angle. Because the kinematical length of linkage refers to the distance between joints connected to the linkage, the linkage length can be adjustable as moving the position of a joint. As mentioned in section 2.2, the frame linkage length can be controlled by using the left-right motion of the rack-and-pinion or the guide rail, and the rotational motion of the cam.

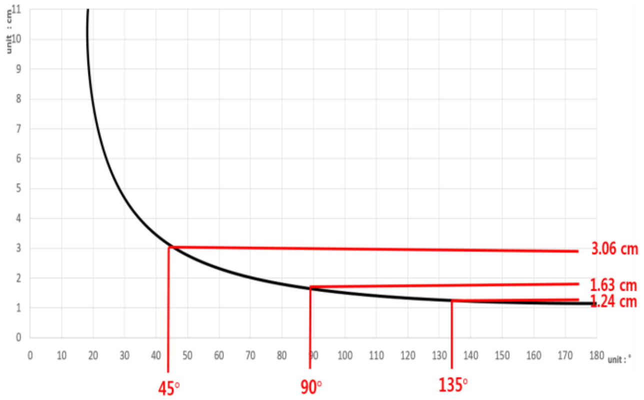
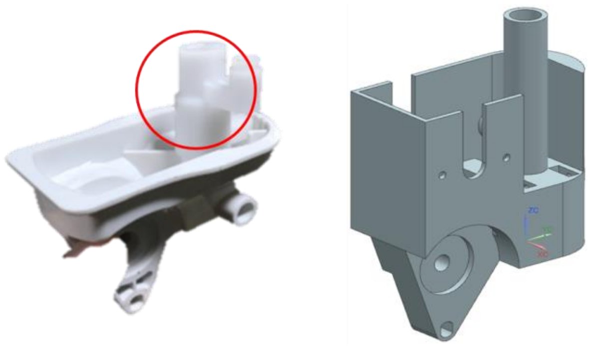


Fig. 10: Required frame lengths according to three levels of turning angle

As shown in figure 10, however, the frame length at each turning level does not change linearly and finer length adjustment is required at large angles compared to small angles. Generally, a rack-and-pinion or a guide rail has a shortcoming that the length adjustment is always constant due to the fixed gear ratio. Therefore, the frame linkage length is adjusted with the rotational motion of the cylindrical cam connected to the frame joint. If a groove with an appropriate path is formed on the cam surface, the frame linkage length can be adjusted according to the turning angles regardless of whether the turning angles are large or small. The cam diameter and the groove path are determined to make the required translation motion of a sliding unit, which is engaged with the groove on the cam.

4. Design and fabrication

Figure 11 (a) shows the oscillation housing of the commercial fan, which supports the fan head and the frame. The big post is connected to the front motor and the small post is connected to the fan deck, and the distance between two posts represents the frame linkage length. The current frame length is constant and it is only capable of one step turning angle. To set the variable frame length for multiple levels of turning angles, the oscillation housing was first modified, as shown in figure 11 (b). The overall dimension of the oscillation housing was maintained for consideration of the connection to the fan stand and the inner shape was redesigned for the cylindrical cam and the sliding unit. The big post of the commercial housing was extended to the bottom of the housing and the small post was removed and repositioned to the sliding unit.



(a) Commercial oscillation housing (b) Modified oscillation housing

Fig. 11: Oscillation housing of commercial fan and modified oscillation housing for variable linkage mechanism

Figure 12 shows the 3D modeling of the final assembled housing with the driving units and its fabricated shape, designed to be capable of adjusting the frame linkage length.

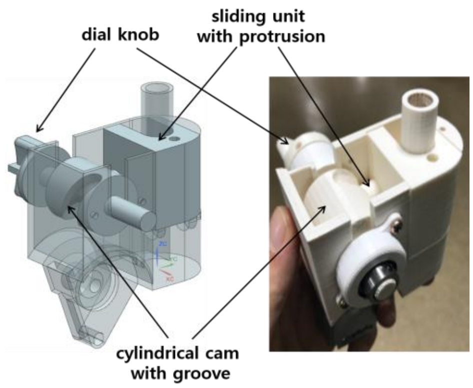


Fig. 12: 3D modeling of the final assembled housing with the driving units and its fabricated shape

A grooved cylindrical cam with an axis shaft was placed in the rear of the housing and the groove corner was rounded to enable the smooth movement of the sliding unit. For user convenience, the allowable rotation steps of the cam were set to three levels of the fan turning angle. Therefore, the cam diameter and the groove path were designed in order that the sliding unit could be moved for the desired frame length at every single rotation of the cam by 120°. A protrusion was made on the surface of the sliding unit and engaged to the groove on the cylindrical cam. The height of the protrusion on the sliding unit was appropriately designed to fit the groove depth on the cylindrical cam.

To easily turn the cylindrical cam, the dial knob was combined to the one side shaft of the cam. Because the cam diameter and the groove path were designed to make the three levels of turning angle at every single rotation of the cam, three hole-type stoppers that enable the cam to position the desired angle were positioned by every 120° on the bottom surface of the dial knob.

Figure 13 shows a schematic 3D modeling of the variable four-bar linkage system and its fabricated shape.

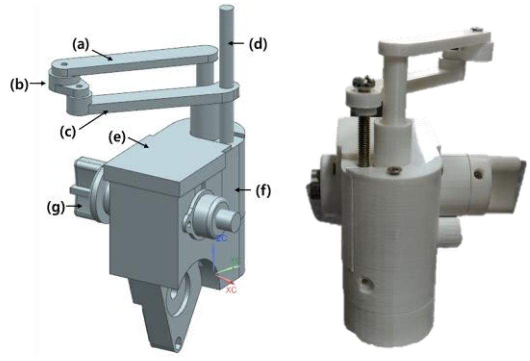


Fig. 13: 3D modeling of the variable linkage system and its fabricated shape

This system comprises of the conventional four-bar linkage device and modified oscillating housing with the driving unit. The four-bar linkage device consists of two lockers, that is, upper (a) and lower rocker (c), a crank (b), and a frame. As mentioned above, the frame is defined as the distance between the parts protruding from the axis of the front motor and the fan neck. Therefore, the distance between the posts of the upper and lower rocker is considered as the frame. The rocker 1 linkage also does not actually exist and is virtually expressed for understanding.

The modified oscillation housing is composed of a housing pivotally connected to the upper rocker, a post (d) that transfers the motion of the sliding unit to the lower rocker, a housing cover (e), a sliding unit (f) pivotally connected to lower rocker, and a motion converting unit (g) that converts the rotating motion of the dial knob into the linear motion of the sliding unit.

Figure 14 shows an operating principle of a variable linkage mechanism.

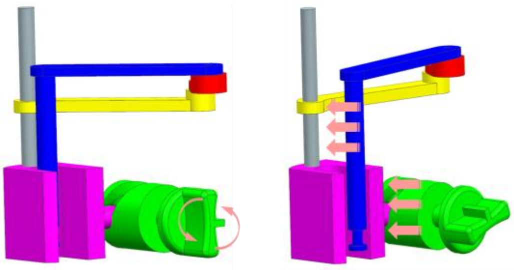
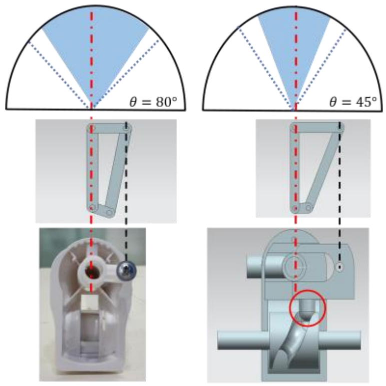


Fig. 14: Operation principle of the variable linkage system

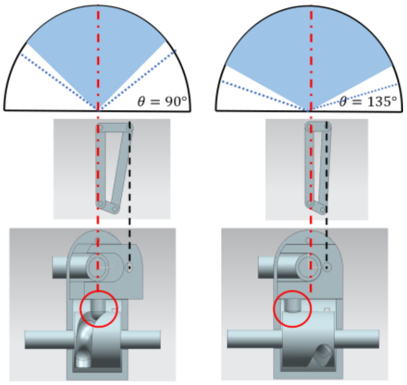
When the dial knob of the motion converting unit is turned, the cylindrical cam rotates and a protrusion formed on the connected sliding unit moves along the groove of the cylindrical cam, which induces the translation motion of the sliding unit.

The shaft of the upper rocker is pivotally engaged with the housing post and its location is fixed. The lower rocker is also combined with the sliding unit and its location can be changed. Consequently, the relative distance between the upper and lower rocker increases or decreases, meaning that the frame linkage length is adjusted.

Figure 15 presents the changes in the frame linkage length and fan turning angles made by the rotation of the cylindrical cam. The fan turning angle of the commercial fan is shown in figure 15 (a). Because the lengths of all linkage are fixed, only one turning angle is provided. Figure 15 (b) to (d) presents the changes in the frame linkage length and the fan turning angle made by the rotation of the cylindrical cam of the variable linkage system. When the dial knob of the motion converting unit is rotated, the frame linkage length is adjusted to 3.06cm, 1.63cm, and 1.24cm leading to the turning of the fan by 45°, 90°, and 135° respectively.



(a) Commercial linkage (b) Modified linkage of 45°

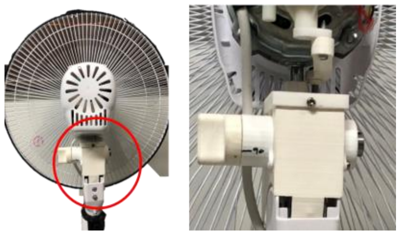


(c) Modified linkage of 90° (d) Modified linkage of 135°

Fig. 15: Changes in the frame linkage length and fan turning angles made by the rotation of the cylindrical cam

Figure 16 shows the real images of the finally assembled variable linkage system installed in the commercial fan. The rocker 1 linkage, virtually expressed in figure 13, was removed and its joints were connected to the axis of the fan neck and the axis of the rear motor, respectively. As shown in figure 16, since this variable linkage system is detachable and perfectly replaced the conventional oscillation housing, no addition fabrication cost is required to install on existing fans.

(a) Side view of the variable linkage system



(b) Rear view of the variable linkage system

Fig. 16: Real images of the finally assembled variable linkage system installed in the commercial fan

The assembled fan was operated to see if the fan rotates as designed. Figure 17 shows the views of the fan fully turned to individual levels when the variable linkage system had been assembled into an actual fan product. It was confirmed that the length was appropriately adjusted by the cylindrical cam so that the fan was operated in the turning ranges of 45°, 90°, and 135°, respectively.

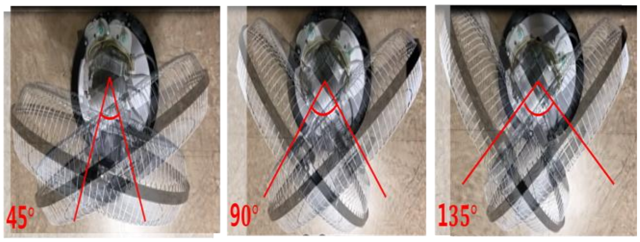


Fig. 17: Assembly into an actual product and measurement of the turning angles

5. Conclusion

In this study, a variable four-bar linkage mechanism that enables to adjust the turning angle of the output linkage to fit desired situations was designed and applied to a table fan to enable the adjustment of the turning angle. Through experiments, it was confirmed that when the fan turning angle was adjusted to the three levels of 45°, 90°, and 135°, the winds did not overlapped, the fan did not turn excessively, and the highest efficiency was achieved. The frame linkage lengths for the individual fan turning angles were 3.06cm, 1.63cm, and 1.24cm respectively. Since the changes in the frame linkage length according to angle adjustment were not linear, the adjustment of the fan turning angle was enabled using the curvature of the cylindrical cam with the appropriately designed groove path. The variable linkage system presented in this study can be turned up to 135° and can be applied to existing fans because it is detachable. In addition to fans, it can be applied to industrial robots or variable valve systems of automobiles and its efficiency can be maximized by increasing the available driving range.

Acknowledgement

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