Anti-Pinch System for Power Window Based on Current Information
전류 정보 기반의 파워 윈도우용 안티핀치 시스템

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Key Words : 파워 윈도우(Power window), 안티핀치 시스템(Anti-pinch system), 미연방 자동차 안전 규정(FMVSS regulation), 전류 정보(Current information), 자동 임계값(Automatic threshold), 반전력(Squeezing force), 홀 전류 센서(Hall current sensor), 접촉식(Contact method)

Abstract : 안티핀치 시스템은 파워 윈도우 상승 시에 인체의 특정 부위가 창문 틈 사이에 끼여 발생하는 치명적인 사고를 방지하기 위한 안전 시스템이다. 이러한 안티핀치 시스템은 물체의 끼임을 검출하는 센서 방식에 따라 접촉식과 비접촉식 두 가지로 크게 구분된다. 본 논문에서는 접촉식의 한 방법으로 전류 정보에 의해 강화된 미국의 안전 규정 FMVSS 118-S5를 만족하는 안티핀치 시스템을 제안한다. 안티핀치 시스템에 사용된 전류 정보는 추가적인 장치의 부착 없이도 기존의 파워 윈도우용 모터 드라이브에 내장된 과전류 검출용 전류 센서를 이용하여 쉽게 얻을 수 있다. 또한 전류 정보는 물체의 끼임을 신속히 검출, 반영함으로써 안티핀치 시스템에 요구되는 반전력 저감에 기여한다. 특히, 본 논문에서는 전류의 임계값이 모터 경년 변화나 운전 조건에 따라 변동하는 문제점을 개선하기 위해 핀치 상태를 효과적으로 판정할 수 있는 자동 임계값 설정 방법을 제안한다. 마지막으로 다양한 실험 및 시험을 통해 제안된 안티핀치 시스템이 FMVSS 118-S5를 만족함을 보인다.

1. 서 론

Power window or electric window is automobile window which can be raised and lowered by pressing a button or switch, as opposed to use a hand-turned crank handle. Power window system that used on the automobile system must meet safety and security standard of operation to avoid fatal accident, for example children neck being trapped, leading to suffocation because of malfunction or usage error of the power window. Some designs of power window place the switch on a hand rest where it can be accidentally triggered by a child climbing to place his or her head out of the window. To prevent these problems, many vehicles install a driver-controlled lockout switch, preventing rear-seat passengers from accidentally triggering the switch.[1)]

In automobile technology, manufacturers should make a system that satisfying certain regulation to ensure passengers safety. There are two most noted regulations for the automobile technology, especially for power window technology. In Europe(EU), all vehicles that have power window system must meet DIRECTIVE 2000/4/EC regulation since 2000. And in 2005, America(USA) strengthened the regulation from Europe that all vehicles which have power window system must meet FMVSS(Federal Motor Vehicle Safety Standard) 118-S5 regulation to satisfy the standard of safety for passengers.[2,3)]

Anti-pinch system is a safety system on power window which has function to prevent fatal

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accidents caused by objects(in this case, human body) stuck or pinched in the window area. Power window operation method is based on on-off switch. These switches enable the DC motor to operate windows down or up where the rotor connected to window mechanical system. When the power windows operate and detect some obstacle on the window area, the anti-pinch system will begin to work and the window will go down automatically.

Currently, there are two kinds of anti-pinch work methods, non-contact method and contact method. Non-contact system detects the position of the obstacle using some sensors(for example, electromagnetic field sensor) to measure proximity distance of the obstacle that enters sensor space-charge field before the window touches the obstacle. Non-contact method is rarely used on the power window that included anti-pinch system because it has high-cost performance despite its technologically more advanced. On the other hand, contact method which senses an obstacle on the window is general method that used to build anti-pinch system. The contact method anti-pinch senses the obstacle by direct touch between windows and obstacles that would affect the DC motor behavior. The most common contact method for anti-pinch system is sensing the DC motor speed variation by using Hall IC speed sensor. When the window is in contact with obstacles the speed of DC motor will slow down and stop, Hall IC as a speed sensor will sense the DC motor speed change and gives feedback to anti-pinch system so that the window will work in opposite direction.

There are some other researches about anti-pinch system that have made. Those systems are considered different with this paper. Those researches used H_∞ filter and Kalman filter in order to detect the obstacle by calculating the angular velocity of the DC motor and recognizing the pinch condition using the torque rate estimation. Both of them were not considered the FMVSS 118-S5 regulation as a standard.[4,5] Also, there are anti-pinch contact method system that used other sensor type, such as stainless steel sensor, TPE(Thermoplastic elastomer) sensor, and capacitive sensor.[6~8] There are some demerits on development of speed based anti-pinch system such as complicated installation of the Hall IC speed sensor and set the effective angular position of the Hall IC speed sensor that used on the system. Moreover, the capability of speed information to reflect pinch condition was not very sensitive. Because of this reason, the system was late to make the pinch state decision. The development of this speed based anti-pinch system was hardware oriented. The system performance was highly dependent on the hardware quality and hardware installation on the system. The installation of the Hall IC speed sensor in this system was complicated because it needs some space inside the DC motor, specifically near the rotor ring magnet.[9]

In this paper, contact method anti-pinch system based on current information is suggested to satisfy FMVSS 118-S5 regulation. Current information which used in this anti-pinch system was detected easily by using current sensor in a motor driver without adding extra devices. Moreover, the current information can reflect the pinch state very quickly. On the other hand, current information has some demerits such as weak to get affected by disturbances that can make noises. In this anti-pinch system, automatic threshold method has been developed to overcome the current noise disturbance. And also, position sensor is used to detect the glass position on the window frame. In this current based anti-pinch system, the important part of the development was on the software development.

Calculations of the squeezing force and control algorithm for the anti-pinch system were created using LabVIEW system. Through some experiments, the anti-pinch system was satisfied the FMVSS 118-S5 regulation. The anti-pinch tests were performed on the window frame area based on the FMVSS 118-S5 regulation to measure squeezing force.

2. Regulation overview and power window anti-pinch benchmark test

Europe(EU) and America(USA) have published a regulation about automobile safety system on power window. This chapter will discuss about power window regulations. European regulation that regulates power window system is DIRECTIVE 2000/4/EC. And American regulation relating to safety standard and comfortability of the anti-pinch system on power window is FMVSS 118-S5 regulation. These regulations regulate the standard limits which must be fulfilled by an anti-pinch system on power window about the maximum amount of squeezing force and the minimum safe reversal distances of the window.

2.1 Comparison of regulations

In the development of automobile technology, regulation improvement is needed to make system safer and more comfortable for the passengers. In this case, America made regulation and strengthened pre-existing European regulation.

Table 1 is explaining about the main idea from DIRECTIVE 2000/4/EC regulation and FMVSS 118-S5 regulation. In these two regulations, value of squeezing force, reversal section, and reversal distance point 1-2 are the same on both regulations, but test rod force deflection ratio and reversal distances point 3 are different. Test rod force deflection ratio is depended on the size of the test rod itself. In FMVSS 118-S5, the test rod is divided into two test rods. This point was made the FMVSS 118-S5 regulation more advanced because by using 65 N/mm test rod, the FMVSS 118 concerns about higher level of danger. For the reversal distances on both regulations, there are 3 points that can be selected depend on the manufacturers. On point 3, the FMVSS 118-S5 has a safer distance when the pinch condition detected. In this paper, point 3 from the regulation is selected as the reversal distance for the power window anti-pinch system.

Table 1 DIRECTIVE 2000/4/EC and FMVSS 118-S5 regulations comparison[2,3]

Item	DIRECTIVE 2000/4/EC	FMVSS 118-S5
Squeezing force	< 100 N	
Reversal section	4~200 mm	
Test rod force deflection ratio	10 N/mm	65 N/mm (≤ 25 mm test rod) 20 N/mm (> 25 mm test rod)
Reversal distances	1. Same position when the window begins to close 2. A position that permits a semi-rigid cylindrical rod which has diameter 200 mm	
	3. A position at least 50 mm more open after the window starts reversing	3. A position at least 125 mm more open after the window starts reversing

2.2 Benchmark power window test

Benchmark power window in this test has an anti-pinch system that used two Hall ICs as a speed sensor. These two Hall ICs are installed around the DC motor rotor where on the rotor mounted two poles permanent magnet. Hall IC position installation can be seen on Fig. 1.

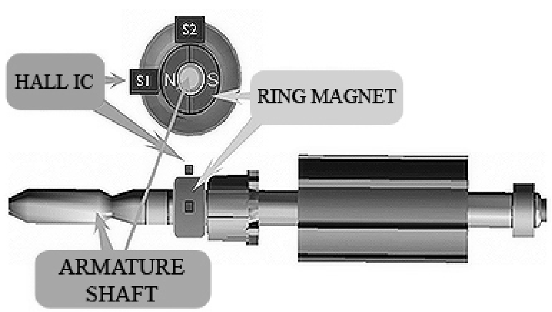


Fig. 1 Hall IC position installation on DC motor rotor of the benchmark system

Squeezing force test was performed on benchmark power window car that already installed anti-pinch system based on Hall speed sensor which satisfying DIRECTIVE 2000/4/EC regulation. Test rod which has 65 N/mm specifications was used to measure squeezing force on the benchmark power window. The minimum squeezing force result for the benchmark power window was 104.5 N. Based on FMVSS 118-S5 regulation, the squeezing force result was over the maximum standard value and this means benchmark power window car does not satisfy FMVSS 118-S5 regulation. In this paper, current based method was suggested to build anti-pinch system that can satisfy FMVSS 118-S5 regulation. In this developed anti-pinch, the current information is obtained directly by using current sensor, which attached on the DC motor driver. The current sensor that used in this research is Hall effect type.

Table 2 Current characteristics of DC motor on the benchmark power window APS

Zone No.	DC motor state	Average current(A)	Window sector area(mm)
1	Starting	1.77	450~442
2	Steady state	1.50	441~201
3	Pinch	1.72	200~4
4	Reverse	-1.30	-125 mm after pinch state

3. Design of current based anti-pinch system

Current based anti-pinch system's working principle is based on the current change of the DC motor that acts as the power window actuator. If there are obstacles on the window area and the window glass touches the obstacles, the DC motor will get load disturbance because of the obstacle that made the DC motor current raising. Current which happened in this phenomenon is larger than the normal DC motor current. If the current value is over the threshold setting, the anti-pinch system will be activated to make the DC motor operates in reverse direction(the window glass will move downwards).

3.1 DC motor current characteristics

In this current based anti-pinch system, Hall IC current sensor was used to detect the current value of the DC motor. The benchmark power window was used to get DC motor current characteristics on anti-pinch system. DC motor current characteristics were divided into four zones shown on Fig. 2 and explained using Table 2.

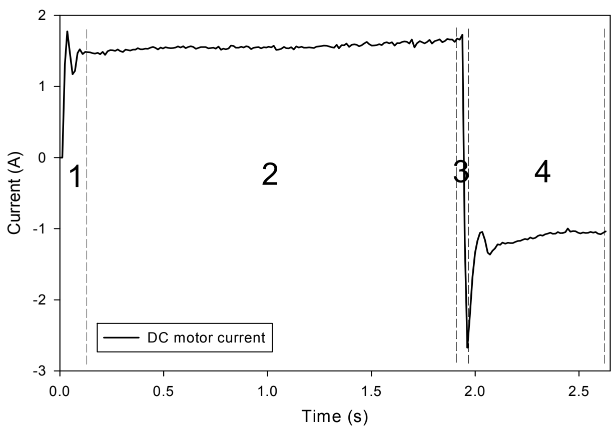


Fig. 2 DC motor current characteristics on benchmark power window APS

DC motor starting current value was big because the motor has inertia and the DC motor current will go to steady state value afterwards. If the obstacle appears on the window area and the window glass touches the obstacles, the benchmark power window anti-pinch system will be activated and the window will go downwards automatically. When the window touches the obstacle, DC motor current will increase because the obstacles act as an additional load.

Current based anti-pinch system can be built by analyzing the DC motor current characteristics. The decision of the pinch state can be performed by applying current threshold on the current based anti-pinch system.

3.2 H-bridge MOSFET circuit as power window switch control

MOSFET switching device was used to control power window movement instead of magnetic contact relay. This is because the reliability and the switching time of MOSFET better than magnetic contact relay. H-bridge MOSFET(Q1~Q4) combination is applied to drive the DC motor forward(window moving upwards) and reverse (window moving downwards). The circuit diagram of the H-bridge MOSFET on developed anti-pinch system is shown on Fig. 3.

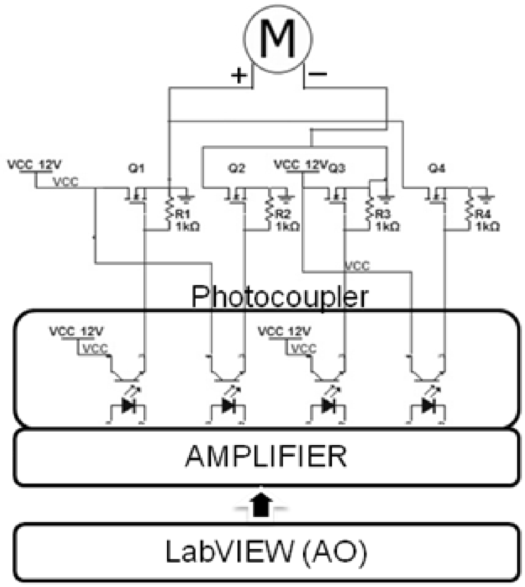


Fig. 3 Anti-pinch system driver circuit using MOSFET

3.3 Anti-pinch working state on window area

Hall IC position sensor is used to detect the position of the window glass so the system can detect the window working area. Based on FMVSS 118-S5 regulation, the window has two areas for the anti-pinch system. The first area is the window stop area. This area is applied if the window touches the obstacle on the area 200~450 mm and 0~4 mm of the window. The second area is the window reversal section. This is applied if the window touches the obstacle on area 4~200 mm of the window frame.

When the obstacle is touched by the window glass on the 4~200 mm area, the window will go downward with the reversal distance as far as 125 mm (point 3 of the reversal distance on FMVSS 118-S5 regulation has been chosen in this experiment). For example, if the window touches the obstacle on position of 200 mm, the anti-pinch system will be activated, and the window will go downward with distance 125 mm and will arrive at position of 325 mm. And the position of 325 mm is also known as the limit for the reversal distance. Fig. 4 shows the anti-pinch system decision on window area.

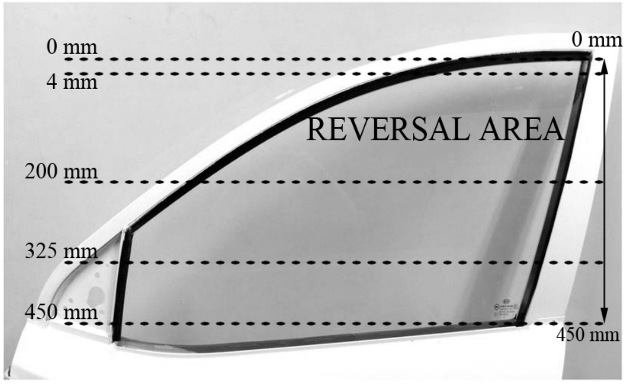


Fig. 4 Working sector area of the anti-pinch system

3.4 Decision of pinch state

In the real system, current amplitude value of the DC motor is always changing depending on the DC motor conditions. Current characteristic of a new DC motor will be different from the used DC motor characteristic. And also the operational timing of the system will cause the DC motor current amplitude to be inconsistent. By using automatic threshold method, the anti-pinch system can overcome those problems.

In this current based anti-pinch system development, automatic threshold is used to detect pinch state that happened in the window. The DC motor current will rise when the pinch condition occurs on the system. If the current is over the threshold, the anti-pinch system will be activated to make the window glass move downwards.

Refers to DC motor current characteristics and anti-pinch system working areas on the window, some of pretests and analysis were conducted to get the best area and calculation equation for automatic threshold setting. The best area to make threshold calculation was on the starting time of the motor. This is because the sample which needed for calculating the threshold can cover the DC motor current characteristics to make the pinch decision if the obstacles appear on the window area. In this experiment, several test was conducted and analyzed to get the best threshold value. The best threshold calculation to detect the pinch condition is 97% from the maximum current value on the DC motor starting time. The equation is shown in equation (1).

$$I_{th} = 0.97 \times I_{\max} \quad (1)$$

Where I_{th} is current threshold and $I_{\max}$ is maximum current value during 0~0.16 s(starting condition).

3.5 Current based anti-pinch system flowchart

Fig. 5 shows the flowchart as a work flow of the power window anti-pinch for the development system. On the flowchart, there are 3 parts explained for the power window to work, up, down, and anti-pinch. The most important part on the flowchart is the anti-pinch part.

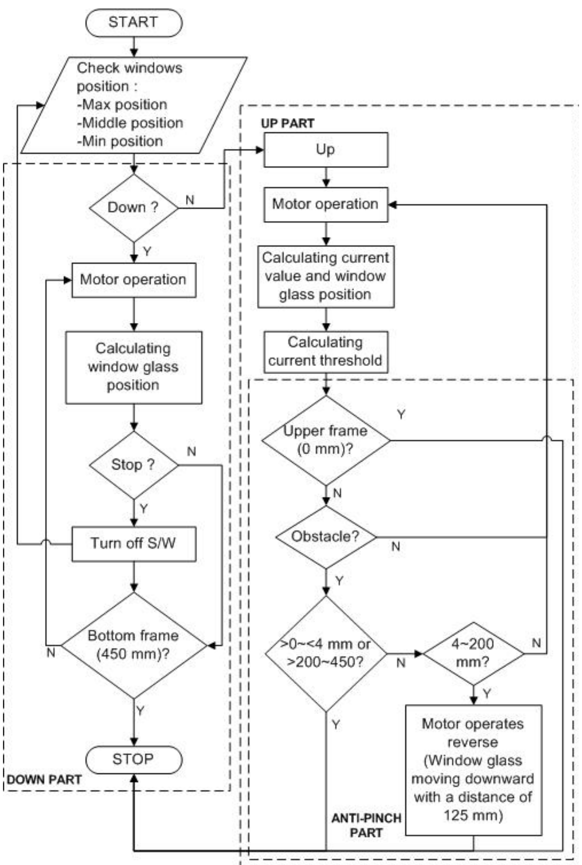


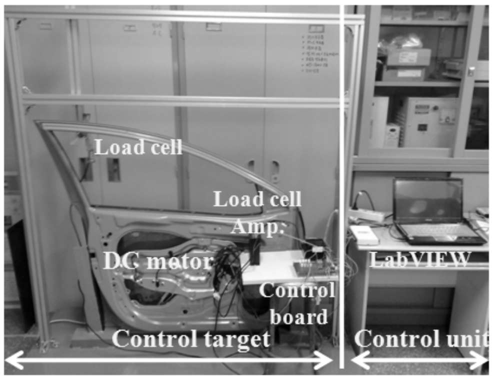
Fig. 5 Flowchart of the designed power window anti-pinch system

4. Experimental methods and results

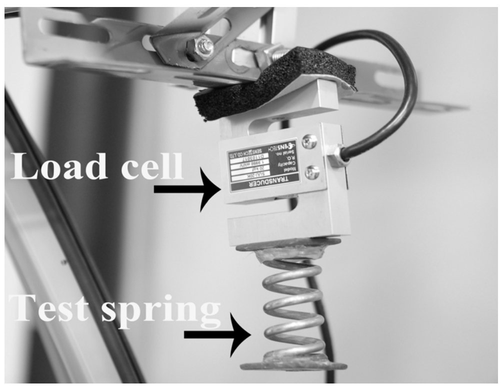
4.1 Experimental apparatus and test methods

LabVIEW program was used to control the DC motor driver and to calculate DC motor current based on the Hall IC current sensor signal output results. Besides for driving the DC motor and calculating the DC motor current, LabVIEW was also used to make program for the anti-pinch system and to calculate the squeezing force of the system.

Load cell was used as a load sensor to detect the power window squeezing force and it was attached on jig. Test spring that attached on the load cell which has same force deflection ratio on FMVSS 118-S5 regulation specification was used as a test rod replacement. Fig. 6 shows experimental apparatus of the power window anti-pinch system.



(a) Experimental wiring system



(b) Load cell and test spring installation

Fig. 6 Experimental apparatus

The test was conducted to measure squeezing force of the window and to make the anti-pinch program satisfying FMVSS regulation. Squeezing force measurement was conducted in the window area based on FMVSS 118-S5 regulation as shown on Fig. 4.

4.2 Experimental results and analysis

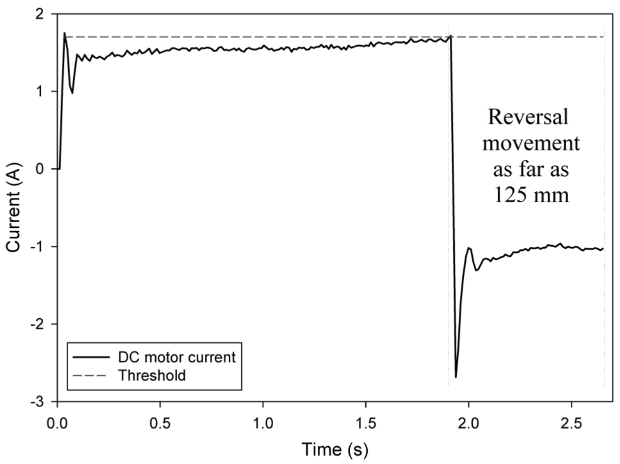


Fig. 7 Real operation time of the anti-pinch system

Anti-pinch in this development used Hall IC current sensor to measure the DC motor current and Hall IC position sensor to check the position of the window glass. Fig. 7 shows one of the experimental results. On Fig. 7, power window system worked from starting point until the window touches the test spring which acts as an obstacle during 2 seconds(0~1.79 s). After the window touches the obstacle, then the window will automatically go downwards and stop after travelling with a distance 125 mm approximately for 1 second(1.8~2.7 s). The measured squeezing force was up to 74.94 N.

Around real operation time in the general tests, the system calculated threshold at the time 0~0.16 s for deciding the pinch condition. When the motor operated after the switch was on, the rotational speed of the rotor was slow for a short time(0~0.16 s) because of the motor inertia and that make the current at the starting point became big. After 0.16 s, the current of the motor changes into a normal state. When the window touches the obstacle, the DC motor current gradually rose and touched the threshold and the window automatically went downwards with a distance 125 mm from the obstacle touching point as shown in Fig. 4.

Table 3 Results of squeezing force tests

Test	Current threshold(A)	Squeezing force(N)
1	1.72	94.67
2	1.69	87.81
3	1.67	52.58
4	1.71	69.51
5	1.72	87.57
6	1.68	63.79
7	1.69	88.65
8	1.70	74.94
9	1.68	79.02
10	1.71	91.73

Table 3 shows the squeezing force value of the developed current based anti-pinch system for 10 tests. From Table 3, the threshold value was always changed according to the operational conditions of the DC motor. In the real operational time, DC motor current amplitude was always changed depend on its conditions. By using automatic threshold calculation shown in equation (1), the anti-pinch system can work during operational times.

Still using Table 3, the squeezing force results from 10 times test were below 100 N. This means the developed current based anti-pinch is satisfying the FMVSS 118-S5 regulation. The benefits of this current based anti-pinch system are having high flexibility, simple structure, and good cost performance comparing to the contact method anti-pinch system based on the speed information.

5. Conclusion

In this paper, current based anti-pinch system was suggested to make improvements for power window system. Improvements were carried out for the system to meet the FMVSS 118-S5 for anti-pinch system on power window. In this anti-pinch system, Hall IC current sensor was used to detect the DC motor current and applied the automatic threshold calculation method to the system. With this design, the system was able to satisfy the FMVSS 118-S5 regulation. Through some experiments, the squeezing forces of the system were below the regulation maximum value(<100 N). The benefits of this current based anti-pinch system are having high flexibility, simple structure, and good cost performance that makes this system economically more competitive than other anti-pinch systems in market place.

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