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Innovative Design of an Automatic Car-Door Opening System

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***Abstract*—To improve the existing mechanism for opening the car-door of a mobile shop vehicle, we first apply the contradiction matrix and the idealized design technique of the Theory of the Solution of Inventive Problems (TRIZ) as a reference to ameliorate an automatic car-door opening (closing) system, and find a scheme matching requirements in design. Next, a motor gear transmission system is designed based on analyses & design theory for motion of a gear train. Finally, an automatic car-door opening (closing) system with design in engineering is devised under constraints in design for automatic opening (closing) of a car door. With the systematic scheme for innovative automatic car-door opening (closing) design evolved to a prototype in this study, the research can be taken as a model for development of an automatic car-door opening (closing) system in the industry.**

***Index Terms*—Automatic car-door opening (closing) system, TRIZ Theory**

I. Introduction

As a result of lower costs for enterprise pioneering and flexible maneuverability, the mobile shop vehicle has been fashionable in recent years. The purpose of this paper is to improve opening mechanism, cut down the cost, and increase the practicability in the industry of a mobile shop vehicle. First, we analyze the structure and car-door opening method of mobile shop vehicle to find any drawback. Then, the design of ameliorating opening of the car-door is conducted. Due to an innovative idea transferred to systematic information, this automatic car-door opening system can be regarded as a model for designing this system with various features such as simple secure structure, long life expectancy, and easily-adjusted & effort-saving opening motions.

II. Literature review

As a reference of designing an automatic car-door opening (closing) system, the existing car frame and tarpaulin [1]-[11] is analyzed and contrasted in this study to summarize relevant requirements, restricted conditions and specifications in design. Divided to both operation mechanisms, human operation and auxiliary-tool operation, for the structure of the car frame and tarpaulin, the former [1]-[5] has complicated structure causing laborious and time-consuming drawbacks and the latter [6]-[11] has defects such as high maintenance and manufacturing costs, short life expectancy, and heavy weight.

Among some patents with respect to the above descriptions, T. S. Chung [11], who used hydraulic cylinder to drive a car frame, improved the wing-type car door structure with advantages of sheltering rainfall and sunshine, larger space due to opening at three lateral sides, and innovative style but shortcomings of complicated opening structure with a hydraulic drive system, high costs, and heavy weight. The ameliorated wing-type car door structure is shown in Fig. 1. Still, the ameliorated wing-type car door structure [11] is selected as an original mechanism in our study expecting to lower costs and increase facilitation in operations in this car-door opening system.

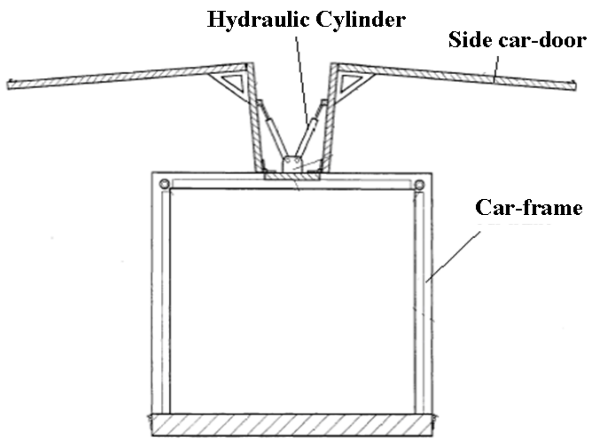

Fig.1. The ameliorated wing-type car door structure [11]

III. Applications of TRIZ Theory

TRIZ, a Russian acronym of “Teoriya Resheniya Izobretatelskikh Zadatch” which means “Theory of the Solution of Inventive Problems”, is developed by a Russian engineer Genrich Altshuller. After reading more than 200 thousand patents, Mr. Altshuller and his colleagues concluded the innovation or invention for an engineering system is not a random event because a person’s capability for invention and creation is trainable. In light of arguments of the TRIZ theory, the general evolution theory available to the technical system can be developed into methods or tools

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to solve originality [12]-[13].

A. Contradiction Matrix

Analyzing more than 200 thousand patents since 1950's, Genrich Altshuller and his colleagues developed the contradiction matrix as one tool to solve contradictions in techniques by inducing 39 engineering parameters and 40 creation principles. Based on the TRIZ theory, the existing systems always contain contradictions and an innovation is materialized with these contradictions excluded from a question. To find a feasible solution principle, Genrich Altshuller arranged 39 engineering parameters into two axes of the matrix wherein the vertical axis contains parameters to be improved and the horizontal axis includes parameters avoiding to be deteriorated. The corresponding grid intersected by both contradiction parameters is the solution principle recommended.

Because the costs for the car-door opening system and the facilitation for operating the original mechanism [11] are expected to be lowered and increased, respectively, parameters to be improved are fixed members' areas (6), power (21) and device complexity (36), and parameters avoided to be deteriorated are fixed members' lengths (4), strength (14) and reliability (27). As shown in Table 1 for the contradiction matrix, the most frequent solution principle is Principle 26, simplified and inexpensive objects employed to replace high-priced ones. For the sake of reducing costs, the manner of opening the car frame is changed to a mechanism driven by motors and connecting rods. As shown in Fig. 2, the scheme for automatically opening a car frame is: The Motor (5) links the Linkage (4), which connects the Car Door (1) with the Linkage joints(3), and the Lateral Car Door (2) forms an angle of 90 degrees with the Car Door (1). Activation of the Motor (5) is able to drive the Connecting Rod Assembly (4) which drives the Car Door (1) to open the Lateral Car Door (2).

Table 1 The contradiction matrix

Worsening Factor / Improving Factor		4	14	27
		Length of stationary object	Strength	Reliability
6	Area of stationary object	26,27 9,39	40	32,35 40, 4
21	Power		26,10 28	19, 24 26,31
36	Device complexity	26	2,13 28	13,35 1

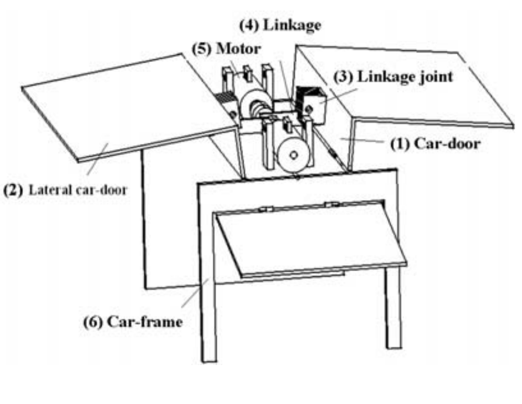

Fig.2. The scheme of automatic opening car door

B. Idealized Design Theory

The concept of idealized design developed by Genrich Altshuller emphasizes that any technical system is always evolved to a simplified, effective, idealized system within its life cycle. Supplying a systematic method to help a designer to correctively define questions, the idealized design theory can generate innovative concepts for idealized targets. Due to six steps for defining and analyzing questions to discover a scheme for settlement in an idealized design, the steps for an idealized design in this study are:

1) Finalized targets for one design: Improvement for opening a car frame, reduction in costs, and increase in practicability for the industry.
2) Idealized solution: Development of a controllable single-side car-door opening (closing) system to realize light weight, lower costs, and no rock of the body with the car frame opened.
3) Obstacles for idealized solutions: Owing to complexity of the hydraulic opening system, the hydraulic cylinder, hydraulic pumps, and pipelines need to be regularly maintained or oil leakage is inevitable. The hydraulic equipment is required to match a vehicle's dimensions and has high costs and weight. Lacking a self-locking function, the car doors without an extra safety device added may cause danger while gradually slipping downward.
4) Results with obstacles occurred: Employment of a hydraulic opening system.
5) Conditions without obstacles occurred: Another opening system to replace the hydraulic opening system.
6) Usable resources for creation of these conditions: Car frame, car doors, motors, and lead screws.

The scheme for idealized solutions based on employment of a displacement system and changes in operation principles:

1) Displacement system: Displace the hydraulic drive opening system in the original mechanism with the motor- and gear-driven opening system.
2) Changes in operation principles: To improve drawbacks in the opening system of the innovative design scheme (Fig. 2) such as members easily eroded, contaminated and occupying large volume as a result of exposure outside a car body and to materialize reduction in costs and simplification of opening operations, the position for the opening system in this design scheme is changed with motors, worms and gears placed on the car frame as well as the linkage changed to an electric motor-gear cylinder, which is driven to open the car door by activation of motor, worm and worm gear.

IV. DESIGN OF THE INNOVATIVE SCHEME

A. The Design of Automatically Car-Door Opening System

The objective of this study is to explore major specifications and functions of an automatic car-door opening system and propose new design concepts as references of designing this system. The automatic car-door opening system includes electric motor-gear cylinders and

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car-door mechanisms. The purpose of this paper is to reduce the volume of automatic car-door opening system and increasing facilitation in operations. The electric motor-gear cylinder is composed of motor, worm and worm gear reducer, and screw pair. The design [14]-[15] for the automatic car-door opening system is described as follows:

1. Electric motor-gear cylinder

(1) The design of worm and worm gear reducer

Based on features of the gear trains, we design the worm and worm gear reducer matching the requirements in speeds of the automatic car-door opening system. Fig. 3 shows the electric motor-gear cylinder including DC motor, worm and worm gear reducer, and screw pair. The worm (Nw = 1) is the input terminal adjacent to DC motor, and the worm gear (Ng = 36) is the output terminal adjacent to a single-thread screw. Hence, the gear ratio reaches a high value of 36 for control of rotating speeds of a worm gear.

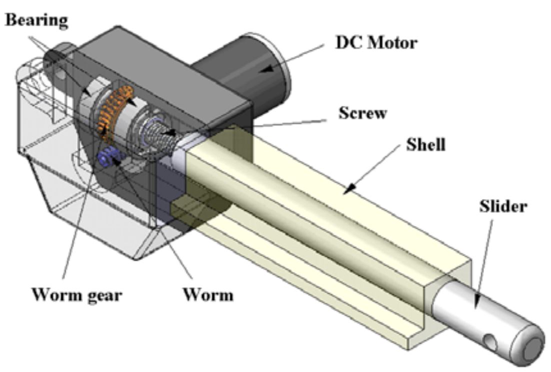


Fig.3. Electric motor-gear cylinder

The motion equation for the worm and worm gear system [16] is:

$$g_r = \frac{\omega_{worm}}{\omega_{gear}} = \frac{N_g}{N_w} \quad (1)$$

With motor's input rotating speed (= rotating speed of worm) $\omega_{worm} = 3600\ rpm$, worm $N_w = 1$, and worm gear $N_g = 36$, substituted into Equation (1), we get:

$$g_r = \frac{3600rpm}{\omega_{gear}} = \frac{36}{1} \quad (2)$$

According to equation (2), the rotating speed of a worm gear at the output terminal is $\omega_{gear} = 100\ rpm = \omega_{screw}$.

(2) The design of screw and slider (nut)

Screw pair is composed of screw and slider. The rotating motion of screw can be changed to the linear motion of slider (nut). It matches the kinematic requirements of automatic car-door opening system. Fig. 4 is the cross-section view of gear box.

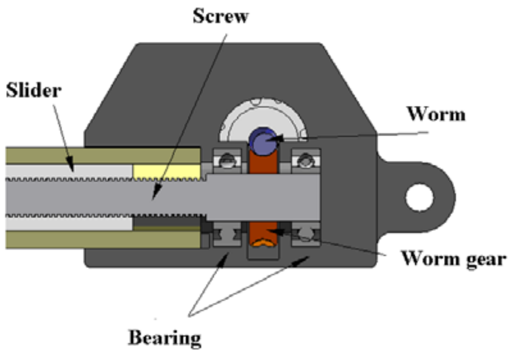


Fig.4. Cross-section view of gear box

The motion equation for the screw and slider is:

$$V_{slider} = L_{screw} \times \omega_{screw} \quad (3)$$

With lead of screw $L_{screw} = 4\ mm$ and rotating speed of worm gear (= rotating speed of screw) $\omega_{gear} = \omega_{screw} = 100\ rpm$, substituted into Equation (3), we get:

$$\begin{aligned} V_{slider} &= 4mm \times 100(rpm) \times \frac{1}{60}(rps/\sec) \\ &= 6.667(mm/\sec) \end{aligned} \quad (4)$$

Thus, the velocity of slider is 6.667mm/sec and that is the lifting velocity.

Based on the above results, the major specifications and functions of electric motor-gear cylinder are shown in Table 2.

Table 2 The specifications for electric motor-gear cylinder

Motor	24V, 70W
Motor's input rotating speed (= rotating speed of worm)	3600 rpm
Teeth number of worm	1T
Teeth number of worm gear	36T
Gear ratio of worm and worm gear pair	36
rotating speed of worm gear (= rotating speed of screw)	100 rpm
Screw lead	4 mm
Linear speed of slider (nut) (Lifting speed)	6.67 mm/s

2. The design of car-door opening mechanism

After the design of motor-gear transmission system, the next work is to design the car-door mechanism. The requirements and specifications of the automatic car-door opening system are described below:

1) The car-door system must have automatic opening functions.
2) Adopt the electric motor-gear cylinders as the power devices of automatic car-door opening system for higher reliability.
3) Add an electric controller to simultaneously control two electric motor-gear cylinders to open each side car-door by user.
4) The rotating speed of DC motor is 3600rpm and the gear ratio of worm and worm gear reducer is 36, hence the rotating speed of output shaft (worm gear) is 100rpm.
5) The lift of the slider is 250mm.
6) The lead of crew is 4mm.

According to the design constraints of automatic car-door opening system, the automatic car-door opening mechanism can be designed by 4-bar linkage (RRPR) which is the inversion of slider-crank. Fig. 5 shows the structure skeleton of the RRPR 4-bar linkage. Link 3 and link 4 forms a prismatic pair and can be substituted by motor-gear transmission system shown in Fig.3.

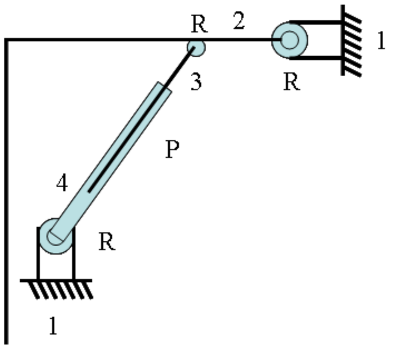


Fig.5. Car-door opening mechanism (RRPR 4-bar linkage)

With the single-side hand-controlled device pressed, the activated motor will drive the electric motor-gear cylinders to work and finally open the car-door because of electric motor-gear cylinders installed between the car-door and the car-frame. The rotating directions of all members in the car-door opening system are shown in Fig. 6.

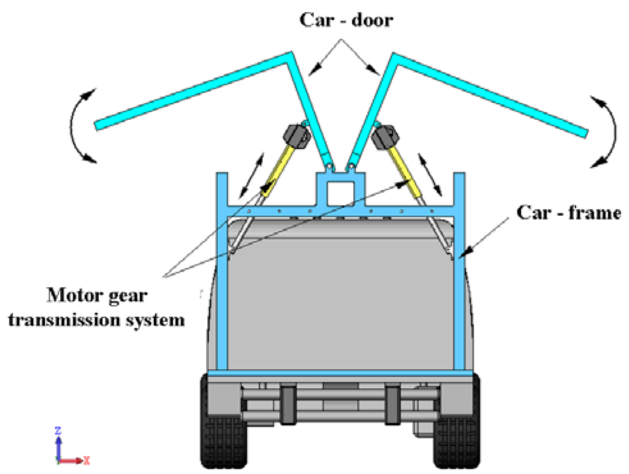


Fig.6. The rotating directions of the car-door opening system

B. *Engineering Design*

In this study, the scheme for design of the automatic car-door opening system covering the electric motor-gear cylinders and the car-door opening mechanisms. The engineering design contains strength design, structure design, and engineering drawing. Fig.7 shows the appearance of electric motor-gear cylinder with total stroke 250mm. The automatic car-door opening system has four groups of electric motor-gear cylinders equipped between car door and car frame. As shown in Fig. 8, the automatic car-door opening system has two electric controllers governing the motion of car-door opening mechanism.

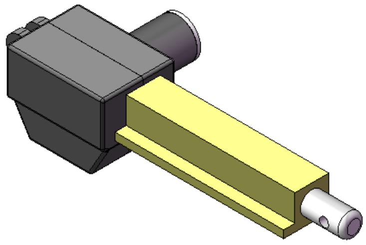
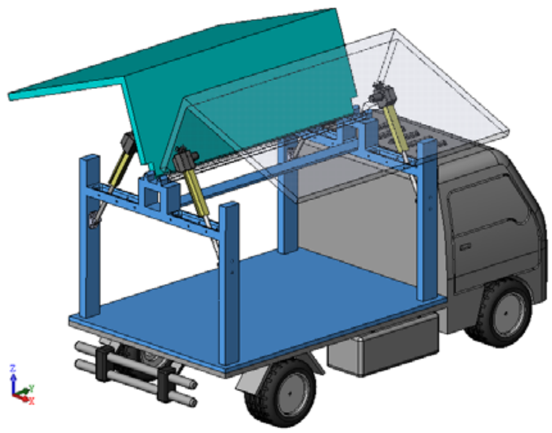
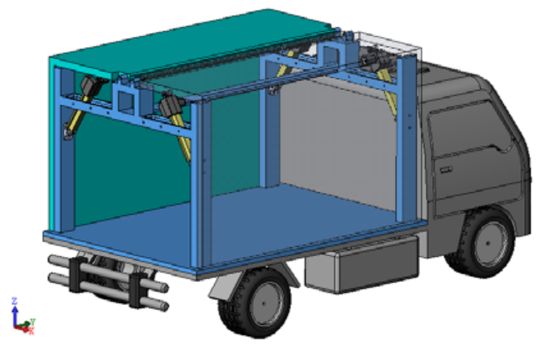


Fig.7. Electric motor-gear cylinder


(a) car-door opening


(b) car-door closing
Fig.8. The automatic car-door opening system

V. Conclusions

Achievements derived from this study:
1) Supply of an innovative process and method for an automatic car-door opening (closing) system as references of systematic design of this mechanism.

2) Design of a drive system for automatic opening of a car door as references of developing an automatic car-door opening system with features like a simple structure, low manufacturing costs and smooth operations.

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