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Reliability Analysis of Abrasion of Ratchet and Paw in Automobile Door Locks

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ABSTRACT: *Automobile door locks are the core components of vehicle safety. Their performance is directly related to personal safety in the use of car.During the locking and unlocking process of the door lock, the pawl and the ratchet, the ratchet and the card, the pawl and the buffer block are all in contact. Under the impact of the locking thrust and the sealing force, some parts of the ratchet pawl may be worn or fatigued, which has a serious impact on the life and quality of the ratchet pawl. For the reliability analysis of the ratchet pawl, the focus of this paper will be on the locking process from the unlocked state to the fully locked state and the unlocking process from the fully locked state to the unlocked state. According to the working principle of mechanism consists of door lock,ratchet and pawl, a mathematical model for analyzing and evaluating the wear reliability of the ratcheting ratchet mechanism is established. The wear failure criterion of the mechanism in the national standard of the door lock is used as the standard, and the general analysis and evaluation of the wear reliability of the ratchet pawl mechanism is given in this paper. In this way, the wear failure probability under different lock unlock times and the reliability function of the ratchet pawl mechanism are obtained.*

KEY WORDS : *Automobiledoor lock, ratchet pawl, wear reliability, reliability function*

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I. INTRODUCTION

Automobile door locks are important accessories for cars, and their operability and reliability are directly related to the use and safety of cars. Therefore, the reliability of the automobile door lock mechanism system must be analyzed and evaluated. In general, the analysis and evaluation of the reliability of the system by the conventional method requires the selection of multiple typical samples, and evaluates the reliability of the system based on a large amount of experimental datain the actual use conditions. Economically and technically, it is impossible to evaluate and analyze the reliability of complex systems. Therefore, it is necessary to establish a probabilistic mathematical model of the system to analyze and evaluate the reliability of the system by means of the probability calculation method based on the test data of typical samples, and refer to the usage information of similar products. In this paper, the failure mode of an existing door lock ratchet pawl mechanism is analyzed, and the mathematical model for analyzing and evaluating the wear reliability is established to derive the wear failure criterion of the door lock mechanism, and the general method of relability analysis and evaluation is given; according to the test data of the existing door lock ratchet pawl mechanism, the wear reliability of the door lock mechanism and its system is calculated, and the wear reliability function of the ratchet pawl is obtained.

1 Failure criterion for ratchet pawl

The mechanism wear reliability refers to the possibility that the actual wear amount of the wear pair is within the allowable wear amount under the specified use conditions within the specified time. During the locking and unlocking process, the upper limit engagement point between the ratchet and the pawl is set to E, and the lower limit engagement point is set to K, and the effective engagement length of the ratchet pawl $|EK|$ is between the upper limit engagement point E and the lower limit engagement point K. During the use of the door lock, as the ratchet pawl repeatedly moves, the amount of wear changes continuously, and the value of $|EK|$ reflects this change.

According to the relevant regulations of GB1058-2013, the door locks are generally equipped with an ideal failure state: in order to ensure the normal use of the door lock mechanism, it is necessary to ensure that the ratchet and the pawl can contact each other. After repeated use, the mechanism can finally reach the limit meshing state when the mechanism is in the fully locked position. At this time, the effective engagement length of the ratchet pawl is $|EK| = 0$, and the door lock cannot lock the door, that means the door lock mechanism wears out. Check the relevant data, we can know that if the door lock can lock the door, the effective engagement length of the ratchet pawl is $|EK| = 0.75mm$. In addition to other factors such as manufacturing error, installation error and safety factor, $|EK| = 2mm$ is taken as the wear failure criterion of the door lock mechanism in practical application.

II. CALCULATION OF RATCHET PAWL WEAR

2.1 Analysis of ratchet pawl force

In the half-locked position, as shown in Figure 2, the force analysis of the ratchet pawl is as follows:

Pawl: The pawl is subjected to the moment M_1 of action of the pawl return spring , the normal force of the ratchet to the pawl at the point of engagement N_1, the frictional force F_1 and the force of the opening rod to the pawl F_0.

Ratchet: The ratchet is subjected to the moment M_2 of the ratchet return spring, normal force N_2 of pawl on ratchet at contact point,the friction force F_2 and the sealing force F_5 of the lock cylinder.

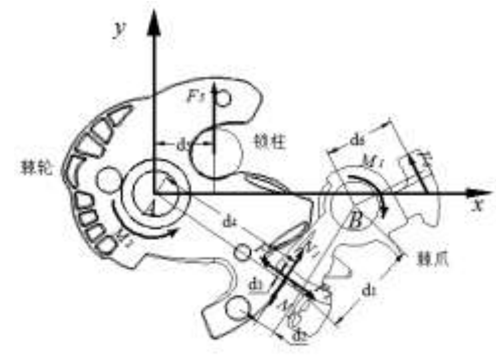
According to the above analysis, the static equilibrium equation of the pawl and the ratchet in the contact state can be obtained:

For pawl: $$\sum M = M_1 + F_1 d_1 + N_1 d_2 - F_6 d_6 = 0 \tag{1}$$

For ratchet： $$\sum M = -M_2 + F_2 d_3 + N_2 d_4 - F_5 d_5 = 0 \tag{2}$$

Where: N_1, N_2 as a pair of forces and reaction forces, their values are the same; Thefriction F_1, F_2 are also the same, and $F_1 = F_2 = \mu N_1 = \mu N_2$, Take the coefficient of friction $\mu = 0.15$, $d_1 = 20.4mm$, $d_2 = 4.16mm$, $d_3 = 0.96mm$, $d_4 = 30.2mm$, $d_5 = 12.27mm$, $d_6 = 14.6mm$, $F_5 = 300N$, $M_1 = 268.1N gmm$, $M_2 = 97.9N gmm$ 。

By substituting the above data into the formulas (1) and (2), it can be obtained $N_1 = N_2 = 124.53N$,when it comes to the semi-locked state, the opening force of the opening connecting rod to the pawl is as follows: $F_6 = 79.95N$



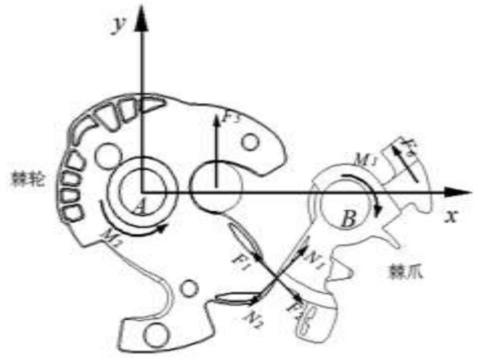


Fig.2 Force diagram of the semi-locking state Fig.3 Stress diagram of unlocking critical state

Similarly, the static equilibrium equations of pawls and ratchets in the critical state of full locking can be obtained. In the critical state of full locking, we select the data as follows: ： $d_1 = 20.4mm$,

$d_2 = 4.23mm$, $d_3 = 0.92mm$, $d_4 = 32.1mm$, $d_5 = 12.27mm$, $d_6 = 14.6mm$, $F_5 = 300N$, $M_1 = 294.3N\cdot mm$, $M_2 = 170.5N\cdot mm$.

The instantaneous opening force of the opening connecting rod to the pawl can be calculated in locking state is obtained: $F_6 = 79.81N\cdot mm$

2.2 Calculation of wear amount

The basic assumption is that ratchet pawl is in normal wear stage.The total wear of ratchet pawls is related to the number of times of repeated use of automobile doors

$$h = Gn \quad (3)$$

.In the formula: h is the total wear amount of ratchet pawl (mm); n is the number of door switches (times); G is the wear amount of door switches (mm/times);

According to Achard formula for calculating adhesion wear, the wear of ratchet pawl is calculated, as shown in Formula (4):

$$W_V = KPS/H \quad (4)$$

In the formula: P is the normal force between ratchet and pawls (N); Sthe relative sliding distance between ratchet and pawls (mm); H is the Brinell hardness (N/mm) of the material of ratchet and pawl ; K is the wear coefficient, which is related to the material of ratchet and pawls.

Among them, S is as follows: $S = nL$ (5)

Where: L is the distance that the pawl slides on the ratchet contact surface every time the door lock is opened, and n is the number of times of opening.

If ΔL near the limit point E-point on the mesh changes, the unlocking wear depth is as follows:

$$\Delta y = \frac{W_y}{b\Delta L} = \frac{KPn}{Hb} \times \frac{\Delta L}{\Delta L} = \frac{KPn}{Hb} mm \quad (6)$$

Where: b is the thickness of the pawl engagement surface (mm)

The average pressure **P** of the ratchet pawl from full engagement to disengagement as the normal force at the engagement point between the ratchet and the pawl. The force analysis of the ratchet pawl shows that:

$$P = (119.47 + 124.53)/2 = 122N$$

Check the relevant books to know: $H = 165N/mm^2$, $K = 1.5 \times 10^{-4}$, b=6mm。SubstitutingP, K, H, b into equation (6), you can get the depth of wear for each unlock： $\Delta y_1 = 1.85 \times 10^{-5}$ ， after be unlocked for n times $\Delta y_1 = 1.85n \times 10^{-5}$, Similarly, the amount of wear that be locked only once: $\Delta y_2 = 22.2 \times 10^{-5}$, Then be locked for n times: $\Delta y_2 = 22.2n \times 10^{-5}$.

There is also wear between the ratchet pawl and the shaft during the process of locking and unlocking.Checck relevant literature, we can know that the annular volume of the cylinder (or hole) wear is:

$$W_V = [\pi(r+\Delta r)^2 - \pi r^2]b = 2\pi r \Delta r b \quad (7)$$

The relative distance between the ratchet shaft and the pawl shaft is:

$$s = (2\pi r)\frac{\Phi}{360°} n \quad (8)$$

From equations (7) and (8), the amount of wear of the shaft and the hole after n rotations in the rotating pair is obtained:

$$\Delta r = 2KP\Phi/(360° bH)\cdot n \quad (9)$$

In the equation: Φ is the angle of relative rotation between the ratchet shaft and the pawl shaft (°); b is the effective contact length (mm) of the rotating pair (as shown in Figure 6-6). By measuring the three-dimensional model of the door lock mechanism, it can be known thatratchet : $\Phi = 87.5°$, $b = 63.95mm$ .paw: $\Phi = 13.25°$, $b = 62.75mm$ .The other parameters are the same as above.

For the hole at the ratchet shaft A, take the same way as the above method to analyse, after be unlocked for n times, $\Delta r_A = 8.43n \times 10^{-7}$ ， Hole at B： $\Delta r_B = 1.30n \times 10^{-7}$ c ， In the same way, the amount of wear on the two axes at A and B can be calculated. Then the change amount of center distance between Aand B axis :

$\Delta AB = 4.865n \times 10^{-7}$. ΔAB is much smaller than Δy , and is negligible in calculation. Therefore, the position and coordinate change of each point in the wear process are regarded as only related to the wear between the ratchet and the pawl.

III. WEAR ANALYSIS AND RESULTS

3.1 Analysis Thought

Based on the rotation center of ratchet wheel **A**as the origin point, a plane rectangular coordinate system is established, the equation of arc or straight line of contact surface between ratchet pawls is obtained, and the coordinates of upper limit contact point **E** and lower limit contact point**K**are obtained.The loss of ratchet return spring and ratchet return spring is negligible after n times of lock and unlock wear during the whole analysis process.

The analysis is as follows: for the loss of ratchet pawl return spring is not counted, the locking position of the damaged ratchet pawl remains parallel to the position before grinding, that is, the basic shape of the contact surface remains unchanged,the radius of the arc of the contact surface is only changed; for the ratchet wheel, although the surface has been worn during the continuous meshing process with the ratchet pawl, there are always new ones to contact the pawl again under the impact of the return spring. Therefore, the pawl and ratchet can always intersect. The intersection point and the distance between the two points can be obtained by combining the curve equation of the edge of the two surfaces.

$$\left|EK\right| = \sqrt{(x_E - x_K)^2 + (y_E - y_K)^2} \quad (10)$$

The key to determine the wear rate of ratchet and pawl is to determine the functionof this change of **E** point coordinates (x_E, y_E) and **K** point coordinates (x_K, y_K) in the wear process.

3.2 Computing Process

The ratchet will move counterclockwise at an angle of 87.5 degrees due to the lock thrust. At the same time, the ratchet will rotate counterclockwise driven by the ratchet.When the ratchet and pawl are out of contact, the ratchet pawl rotates clockwise under the action of the restoring force of its reset spring, and finally re-contacts the ratchet surface, thus reaching the semi-locking state.Compared with the pre-lock ratio, the rotation angle of the pawl is 13.25 degrees.

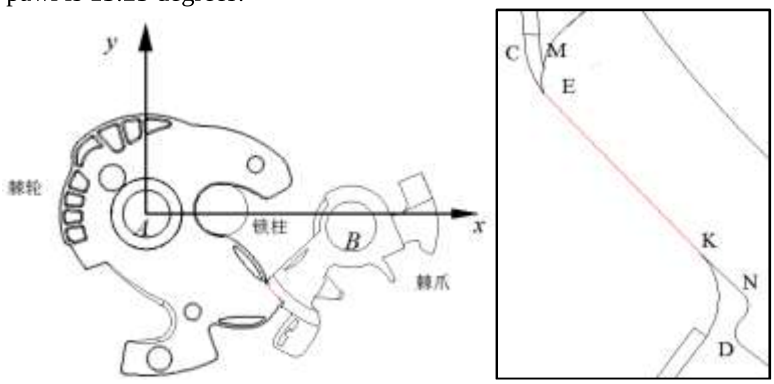


Fig.7 Partial enlarged view of the ratchet pawl contact

The analysis shows that wear occurs in CD segment of ratchet wheel and MN circularsegment on ratchet pawl in the process of locking and unlocking.According to the actual measurement, the initial coordinates of the key points affecting wear and the equations of arcs and straight lines can be obtained.Among them: The center coordinate of ME circular is(26.93, 9.29), and its radius is 0.8mm, The center coordinate of DK is (28.44, 12.16), and its radius is 1.117mm.The original coordinates of E-point is(26.09, 9.87), The original coordinates of K-point is (28.98, 12.41)

Research on pawl: After each wear, it returns to the initial position, the coordinate of the center of the remains unchanged, but its radius decreases gradually, and the lock-unlock wear is $\Delta y = 22.2 \times 10^{-5}\,mm$ every time.Let E point coordinate After n times lock-unlock wear,the change rule of the coordinate of the point E (x_E, y_E) is : E is the intersection of point arc EN and line ME, and the equation of them should be solved simultaneously.Therefore, after n times process of locking are unlocking, the coordinates of point E are one of the solutions of the following equations (the intersection point on the left side of the two lines):

$$\begin{cases} ME:(x-26.93)^2+(y-9.29)^2=(0.8-22.2\times10^{-5}n)^2 \\ EN: y=0.879x-13.063+1.245\times10^{-6}n\Delta y_{开} \end{cases} \quad (11)$$

The main purpose of ratchet wear calculation is to find out the change rule of K coordinates on ratchet wheel.Research on ratchet wheel: Let The change rule of the coordinate of K point after n times lock and unlock wear: K is the intersection point of point arc KN and line DK, the equation of both should be solved together.Therefore, after n times of the process of locking aand unlocking, The coordinates of the the K-point are one of the solutions of the following equations (the intersection point on the left side of the two lines):

$$\begin{cases} DK:(x-28.44)^2+(y-12.16)^2=(1.117-22.2\times10^{-5}n)^2 \\ KN: y=0.879x-13.063+1.245\times10^{-6}n\Delta y_{开} \end{cases} \quad (12)$$

3.3 Reliability analysis results

For the effective locking length between ratchet and pawl is a complex random function of its original size and wear, it is impossible to write its analytical expression, distribution type and distribution parameters.In this paper, Monte Carlo method will be used to simulate statistics, calculate a series of values, and then estimate the mean and mean square deviation, so as to calculate the reliability of ratchet pawl in different locking and unlocking times.

According to the relevant provisions of GB1058-2013, the effective locking lengths calculated by taking the number of door locks n(1.0，1.1，1.2，1.3，1.4（$\times10^5$ ）)into the program and the effective locking lengths are 2.8210 mm, 2.7620 mm, 2.4192 mm, 2.1862 mm and 2.0021 mm, respectively.At this time, the reliability of the door lock mechanism is 100%, and it will not fail.

The table lists the results of simulation calculation of switching times n from 145000 to 150 000 and 500 is the length of each step.

Table 1 Ratchet Claw Reliability

Switching times n	$\|EK\|$ Mean (mm)	$\|EK\|$ standard deviation	Reliability	$\lg\frac{1}{1-R}$
145000	1.9628	0.0381	0.9986	2.8539
145500	1.9543	0.0384	0.9904	2.0177
146000	1.9462	0.0386	0.9812	1.7258
146500	1.9370	0.0381	0.9715	1.5452
147000	1.9286	0.0389	0.9542	1.3391
147500	1.9198	0.0390	0.9476	1.2807
148000	1.9124	0.0392	0.9324	1.1701
148500	1.9036	0.0392	0.9188	1.0904
149000	1.8955	0.0391	0.9098	1.0447
149500	1.8867	0.0397	0.9012	1.0052
150000	1.8782	0.0402	0.8954	0.9805

According to the calculation results in Table 1, the reliability function of ratchet-pawl mechanism is fitted by least square method.

$$\lg\frac{1}{1-R}=1.4927\times10^{-5}n-2.1416n^2+1.0243\times10^5n^3 \quad (13)$$

The variation curve of reliability with the number of locks n is as follows:

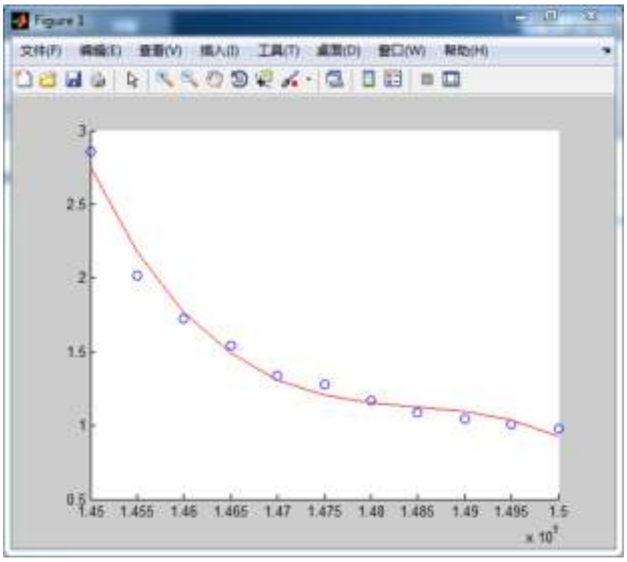


Fig. 6-10 Reliability Curve of Ratchet and Pawl with the Number of Switches n of DoorLock

IV. CONCLUSION

The ratchet and pawl are the core componenst of the door lock system, and its reliability is very important to the whole door lock.Aiming at the reliability of ratchet pawl wear during the use of door lock, this paper mainly completes the following tasks:

(1) Based on the actual situation of ratchet pawl engagement in door lock and the basic theory of parts wear, a mathematical model for analyzing and evaluating wear reliability is established, and the wear failure criterion of door lock mechanism system is derived.

(2) By analyzing the position change and force distribution between the ratchet and pawl during the unlocking process, the wear amount of the locking mechanism of the ratchet and pawl of the door under different working conditions is obtained.

(3) A mathematical model for evaluating the wear reliability of door lock mechanism is established by combining the Monte Carlo simulation method with the calculation of wear quantity of the parts. The wear reliability analysis results of door lock mechanism are obtained by taking the wear failure probability of ratchet pawl after repeated movement as the criterion.

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