Reliability design of vehicle wiring harness

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Abstract. This paper introduces the method of the reliability design of vehicle wiring harness system, and puts forward some feasible schemes on the reliability design of wiring harness, and combines the reliability requirements into the design, so as to reduce the reliability defects caused by unreasonable design and fundamentally improve the reliability of wiring harness system.

1. Introduction
The concept of reliability originates from the field of military equipment, which is an important index of the product as well as its basic performance.

Definition of reliability: the ability of a product to perform specified functions under specified conditions and within specified time. From an engineering perspective: Reliability is defined as a product's ability to complete tasks without failure. From a statistical point of view: the probability of completing a specified function without failure at a specified time and under given conditions. For vehicles, reliability is generally considered as follows: vehicle durability, failure probability, difficulty and cost of maintenance after failure [1].

The reliability of vehicle has become an important index of vehicle performance, and the reliability design of wiring harness has become an important part in vehicle design.

2. Reliability analysis of circuit design
The electrical system of the whole vehicle is composed of one electrical circuit, and the reliability of the circuit is the foundation of the reliability of the wiring harness of the whole vehicle electrical system. In the vehicle wiring harness, each circuit is connected in parallel, but when investigating the reliability of wiring harness, all wiring harness can be regarded as a series circuit, that is, only when all wiring harness circuits are normal, the whole electrical system can operate normally [2].

2.1. Reliability model of loop design
In the vehicle electrical system, there are many assemblies and circuits involved in the completion of a function. For example, the backlight is related to several assemblies such as power supply, backlight, control box and dashboard. In a group of wire harness, there will be several or even dozens of wire harness circuit, the reliability of each circuit is related to the reliability of the whole assembly and even the whole vehicle.

If we take the whole system as the total system, the total reliability is R(t), and the reliability of each assembly is R1(t), R2(t)... Then Rn(t) can be used to obtain the reliability model of the whole system: R(t) = R1(t) × R2(t) × R3(t)... × Rn(t)
Assembly reliability $R_i(t)$ by each loop in the Assembly $R_{i1}(t), R_{i2}(t)... R_{im}(t)$ decided that $R(t) = R_{i1}(t) \times R_{i2}(t) \times R_{i3}(t)... \times R_{im}(t)$

$$R(t) = \prod_{i=1}^{m} R_{ij}(t)$$  \hspace{1cm} (2)

The overall reliability of the entire electrical system can be obtained:

$$R(t) = \prod_{i=1}^{m} \prod_{j=1}^{n} R_{ij}(t)$$  \hspace{1cm} (3)

2.2. Reliability design method of electrical design

The above data show that the number of circuits corresponds to the reliability of the entire electrical system geometrically, and reducing the number of circuits can reduce the failure rate and improve the reliability of the electrical system. However, the reduction of circuits should not be achieved at the expense of the vehicle's fuel consumption and safety indicators. Instead, it should be achieved through the improvement, consolidation and modular processing of circuits and components, and the reduction of circuits, components and connectors.

In the vehicle, different systems and functions have different reliability requirements, such as steering control system, braking system, safety-related ABS, ESP and other reliability requirements must be high, while some systems, such as fans and air conditioners, have relatively low reliability requirements. The reliability requirements of different systems on the vehicle are differentiated, and different designs are applied to determine the reliability distribution of each system in the whole vehicle system, which can effectively reduce the cost.

3. Reliability analysis of terminals and connectors

Terminals and connectors are important parts of the whole wiring harness, and also important contents to determine the reliability of the system. Among the terminals and connectors, a variety of faults are concentrated, including solder joints and connection points. Some terminals and connectors have a bad working environment, which is easy to be corroded, aged and loosened under the action of vibration stress. In the fault of the entire electrical system, the fault caused by the damage, failure, looseness and falling off of the terminals and connectors accounts for about 50% of the total fault, so the reliability design of the terminals and connectors is also an important part of the safety design of the electrical system of the whole vehicle [3].

3.1. Failure modes of terminals and connectors

Analyzing the failure mode is the basic means to improve the reliability. Only by understanding and mastering the possible failure of the product, can the corresponding prevention work be done well.

There are three main faults in terminal and connector: bad contact, bad insulation and fixed fall off. The purpose of reliability design is to reduce the probability of failure.

The failure forms of terminals and connectors mainly include: increased contact resistance, open circuit, short circuit and insulation resistance decline, increased plug and pull force, shortened life, increased voltage standing-wave ratio, fire, etc. The causes of the three failure modes are as follows [4]:

$$R(t) = \prod_{i=1}^{n} R_i(t)$$  \hspace{1cm} (1)
Table 1. Failure modes for terminals and connectors.

| The fault performance | Reason |
|-----------------------|--------|
| Poor contact          | The main body or compression cavity is broken. |
|                       | The socket flange becomes thin or scarred, causing the socket to break and reducing the contact pressure. |
|                       | The material strength and elasticity of needle and socket are not good. |
|                       | Insert needle bent or jack eccentric. |
|                       | Improper end connection. |
|                       | Elastic material stress relaxation, resulting in reduced contact pressure. |
|                       | Poor surface coating, surface wear and mechanical damage, surface arc burning, coating corrosion, contact surface pollution. |
| Insulation fault      | The insulation layer has leakage path, the insulation parts and potting materials are mixed with metal or other exported particles, and there are cracks or bubbles in the insulation parts. |
|                       | Insulation parts have poor moisture resistance. |
|                       | The performance of insulating parts is destroyed under the action of environmental stress. |
|                       | The pin is bent out of shape or there are conductive particles between the contacts, resulting in short circuit. |
|                       | Insufficient insulation distance between contact parts, shell and outer contact parts. |
|                       | Improper operation or forced insertion or removal may cause bending deformation, damage or looseness of the insertion needle. |
| Fixed loose           | Excessive assembly tolerance. |
|                       | The main body or compression cavity is broken. |
|                       | The socket wears away and the surface contact force decreases. |
|                       | Element design itself is not reasonable, failure under environmental stress. |

3.2. Reliability detection of terminals and connectors
For bad contact, static contact resistance should be detected. Dynamic contact resistance; Instantaneous break detection; Vibration resistance of connection points and components; Single hole separation force detection, in the selection of components for some key models of products to carry out 100% point by point conduction test.

The main testing items for defective insulation are: insulation resistance inspection of insulators; Dimensions of insulators, contacts and other parts; Insulation resistance under various environmental stresses (temperature, humidity, etc.); Time degradation rate of insulator.

The reliability detection for fixed loose class mainly includes: assembly tolerance of terminal and connector; Torque test; Insertion force of connecting needle; Holding force of connecting needle; Environmental stress (vibration, temperature, humidity, etc.).

3.3. Means to improve the reliability of terminals and connectors in design
To improve the application reliability of the product, the following points should be paid attention to in the process of selection and assembly:

Select the appropriate electrical connector. Electrical connectors can be selected according to the characteristics of electrical connectors, in addition to the composition of the device and considering the type and number of connection circuits. For example, the circular connector is less affected by climate and mechanical factors than the rectangular connector, has less mechanical wear under the same conditions, and the end connection with the wire or cable is more reliable.
The maximum operating current and total load current of a connector are usually determined based on the amount of heat allowed at the highest ambient temperature and for long periods of operation. Therefore, when selecting connectors, the working conditions of the equipment should be considered. For the use of plug-ins in corrosive gas and liquid environments, attention should be paid to the vertical side horizontal installation as far as possible to prevent corrosion. If the electrical connector must be installed vertically, a slightly higher installation bottom should be provided and the wiring should be downwards to prevent water from flowing into the electrical connector along the lead line.

4. Reliability design of wire harness protection
Circuit design mainly includes: the protection of wire wound and fixed, because on the vehicles, wiring harness work environment is very bad, high temperature, high humidity, vibration, corrosion and other parts of the friction, collision and aerosols, the existence of liquid, may produce insulators wear, loose connection, wire the phenomenon such as corrosion, cause a short circuit, open circuit or even fire consequences, etc. For the harness to work safely and reliably, it must be bandaged and fixed.

In the whole vehicle wiring harness wire harness, should be moisture-proof, anti-corrosion protection measures, especially the engine wiring harness, should have high temperature resistance, corrosion resistance, good sealing protection material closed wiring harness and plug; The wiring harness of other parts should be bundled and protected and installed in a hidden position. The harness should be fixed on the car with a tie belt and a wire clip to reduce the impact of vibration on the wiring harness. Wherever the wire harness passes through the wire hole, it must be protected to prevent friction between the wire hole and the wire harness and damage the insulation layer.

The main means to improve the reliability of protection design are as follows: first, the packaging materials should be subjected to accelerated life test under various stress environments during design and selection. The guiding principle of the test is to conduct tests on a number of dressing materials according to the environmental stress of different parts, and select the one with the best comprehensive performance. The second is to carry out environmental screening test before assembly to prevent unqualified products from entering the next link.

5. Wire harness length design
Generally speaking, the length of wire harness is determined according to the actual position of electrical equipment on the car body. In the assembly process, all places passing by wire harness on the car body have fixed clips or straps to fix wire harness. Therefore, the influence of the size of each branch of the wire harness on reliability is also very important. If the wire harness is long, it will not only waste material and space, but also easily cause contact friction with other parts, so that the wire harness wear and cause short circuit, or even cause a line fire. If the wire is too short, it will make it difficult or even impossible to assemble, especially if the operator tries to tighten the wire by force. The hidden damage is very large, which can easily lead to the looseness of terminals, unreliable connection, and looseness of terminals from the sheath, etc., directly causing the decrease of reliability. Therefore, the length of the wire harness should be slightly redundant according to the actual length of the line. Generally speaking, the redundancy should be between 3-5%.

Conclusion
This paper introduces the method of the reliability design of vehicle wiring harness system, and puts forward some feasible schemes on the reliability design of wiring harness, and combines the reliability requirements into the design, so as to reduce the reliability defects caused by unreasonable design and fundamentally improve the reliability of wiring harness system.

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