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Research on Reliability Allocation Method Of RV Reducer System

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Abstract: Reliability allocation is an important part of the reliability design on RV reducer system, and the result directly affects the design of the whole machine. In order to accurately grasp the RV reducer reliability optimization allocation results under certain constraint conditions, the reliability allocation method based on the RV reducer is established. Firstly, according to the fault analysis results of FTA and FMEA, the fault comprehensive factors of each component are determined. Secondly, the reliability target is assigned to each part according to the certain mathematical relation. The overall reliability of the RV reducer system which is effectively assigned to the various parts is achieved. The method not only combines the two ways of fault analysis with FTA and FMEA, but also improves the original reliability allocation function, and it can also improve the distribution efficiency of reliability and make the distribution result more reasonable.

1. Introduction

The overall reliability index of rules in the product development process is assigned to each subsystem and components with the way of top-down and stepwise decomposition. In this way it can meet the requirements for the reliability of products under the constraints of structure, performance and cost. Based on the theory and analysis method of fault model for RV reducer, the reliability evaluation of RV reducer is carried out according to the working condition and service condition. The reliability of RV reducer is allocated by related methods, so as to improve the reliability level of the whole machine.

2. Failure correlation analysis of RV reducer

In practical engineering applications, the working environment of RV reducer is relatively poor, the connection relationship between parts is relatively complex, and the causal relationship between faults is relatively complex. The failure of the unit at the bottom which influences subsequent failures compound should be taken into account for its criticality. Meanwhile, the failure of multiple units at the same time can cause the cascading faults to form the status of net propagation^[2]. The analysis of FTA and FMEA alone has some shortcomings, such as inadequate expression, lack of consistency and complicated modeling process, so it is difficult to evaluate the relationship and influence of failure modes comprehensively. In order to describe the failure mode of RV reducer in actual condition more accurately and clearly, the comprehensive analysis method of FTA and FMEA is used to provide the theoretical basis for the reliability allocation of RV reducer.

2.1 FTA analysis of RV reducer

The fault tree analysis of the RV reducer aims to simplify the logical relationship between the events. The form of fault tree which was simplified using fault tree analysis method is shown in Fig 1. The



corresponding factors that can cause the failure of the RV reducer are shown in Table 1, that is to say the bottom event.

Since the fault tree has two layers which include the minimum cut set layer and the basic event layer, the reliability allocation of the RV reducer needs two steps, that is, the so-called two assignment model. The reliability of the RV reducer system is assigned to each bottom event, and then the reliability that is obtained from the bottom events is assigned to each basic event corresponding. Finally, the reliability distribution of the whole RV reducer system is achieved [3].

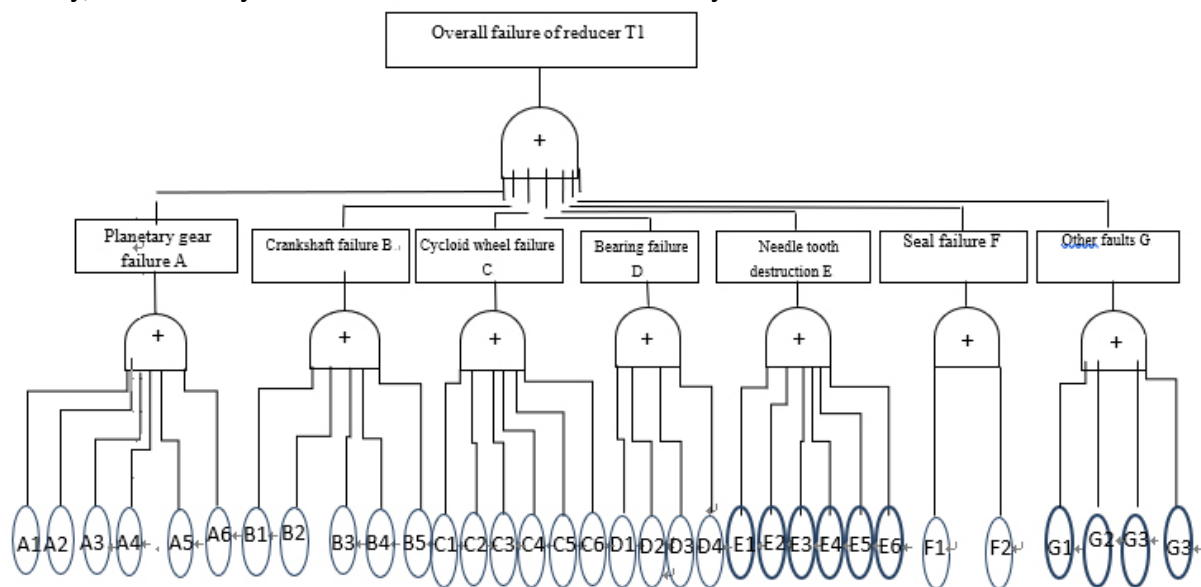


Fig. 1 Fault tree diagram of RV reducer system

Table 1 the corresponding event table in the fault tree

Code	Event	Code	Event	Code	Event
A1	tooth breakage	C1	Cycloidal gear static breaking	E2	Fracture of pin sleeve
A2	Extended pitting	C2	Fatigue fracture of cycloidal gear	E3	Pin gear shell cracking
A3	Tooth surface wear	C3	Gluing of pin gear sleeve and cycloidal gear	E4	Pin and sleeve gluing
A4	Scuffing of tooth surface	C4	Pitting corrosion of cycloidal gears	E5	Pitting of pin teeth and sleeve
A5	Tooth plastic deformation	C5	Wear of cycloid gear surface	E6	Pitting of pin teeth and cycloidal gears
A6	Tooth surface crack	C6	Cycloid gear plastic change	F1	Seal wear
B1	Bend	D1	Bearing wear	F2	Seal aging
B2	Instability	D2	Bearing corrosion	G1	Shell cracking
B3	Center of gravity offset	D3	Bearing fracture	G2	Loosening of fastening bolts
B4	Scratch big	D4	Bearing gluing	G3	Cracking of spacer ring
B5	Break	E1	Pin bending	G4	Circlip damage

Through the fault tree analysis of RV reducer, the fault forms of its main components were obtained. There are more bottom events of the planetary gear, crank shaft, cycloid gear and pin gear system corresponding, so the relative probability of failure is larger.

2.2 FMEA analysis of RV reducer

The Fault data of RV reducer was collected from the cooperation enterprises using field test method. Through the fault data was analyzed and sorted with the help of the clear fault criterion and counting principle, the all fault forms of the RV reducer are obtained. Therefore, the comprehensive analysis result of FMEA of RV reducer is shown in Table 2

The maintainability of Table 2 is divided into 5 grades according to the influence degree which the failure mode of the RV reducer affects the whole machine. The scoring criteria and detailed rules are shown in Table 3, the supportability grading rules are shown in Table 4, and the breakdown rate grading rules are shown in Table 5.

Table 2 FMEA comprehensive analysis table of RV reducer

Component name	Failure mode	Failure impact analysis	Inspection mode	Failure rate	Maintainability analysis	Supportability analysis
Planet gear	Break	Reducer failure, noise increase and abnormal running	Visual inspection	III	IV	III
	pitting	severe noise	Instrument inspection	II	II	II
	abrasion	Machine vibration increased	Visual inspection and instrument test	III	III	IV
	Glue	Vibration and noise increase ,Even a serious death phenomenon	Instrument measurement	III	III	II
	Crackle	cause gear break easily, Failure of whole machine	Inspection of precision special instruments	II	II	II

Table 3 Basis and detailed rules of maintainability score

Category Grade	Maintainability grade	Severity of failure
I	Product no fault, Change its usage environment only	Almost no impact on the whole machine
II	Product no fault, Planned maintenance	Slight fault in the product, Does not affect the normal work of the product
III	Disassembly products, replacing vulnerable components	The product work improperly, But it works accompanied by vibration and noise
IV	Disassembly products, Replacement of important components	The product can barely turn and accompanied by huge vibration and noise
V	Change product	The product cannot rotate

Table 4 basis and detailed rules of supportability score

Category Grade	Supportability grade	Basis of Supportability Division
I	Minimum guarantee	Minimum maintenance level, the minimum probability of fault occurrence ,and high probability of fault detection;
II	Minor guarantee	Planned maintenance of products, the lower probability of fault occurrence, and moderate probability of fault detection;
III	Medium guarantee	Moderate damage to the product, the moderate probability of fault occurrence, and low probability of fault detection;

IV	Major guarantee	Serious damage to the product, the high probability of fault occurrence, and low probability of fault detection;
V	Maximum guarantee	Product damage, resulting in significant property losses ,very high probability of fault occurrence, unable to detect fault

Table 5 grading rules of failure mode occurrence probability level

Reference range of failure mode occurrence probability p_m	Possibility of failure mode occurrence	Rating scale
$p_m \leq 10^{-6}$	Very low	I
$1 \times 10^{-6} < p_m \leq 1 \times 10^{-4}$	Low	II
$1 \times 10^{-4} < p_m \leq 1 \times 10^{-2}$	medium	III
$1 \times 10^{-2} < p_m \leq 1 \times 10^{-1}$	high	IV
$p_m > 10^{-1}$	Very high	V

Based on the FMEA comprehensive analysis of RV reducer, the fault occurrence rate, maintenance level and supportability level of the main components were obtained. The degree of the main fault forms of each component that influences the whole machine was also obtained. All these can provide a theoretical basis for the reliability allocation of RV reduce.

3. Reliability allocation of RV reducer

3.1 Reliability allocation process of RV reducer

The basic flow of the reliability allocation of the RV reducer is shown in Figure 2.

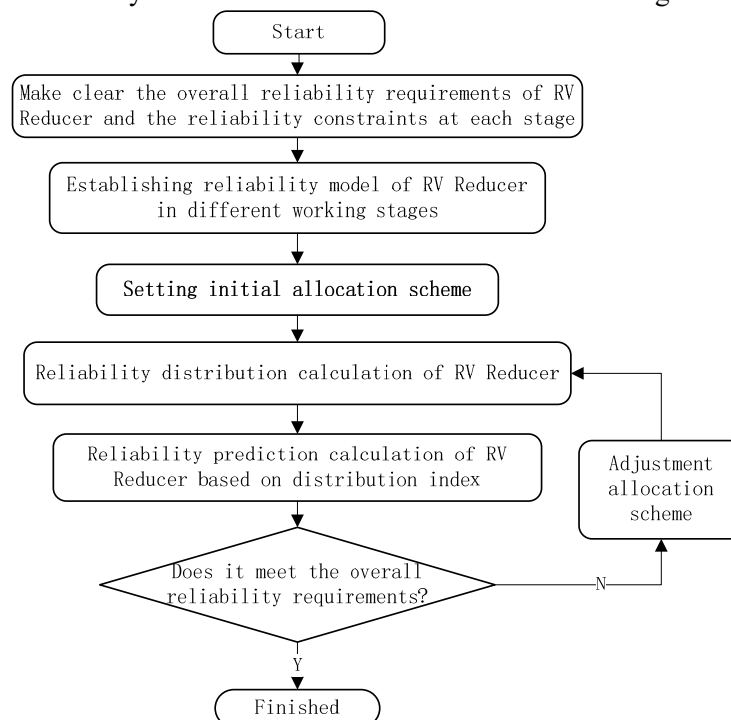


Fig. 2 Reliability allocation flow chart of RV reducer

3.2 Reliability allocation of RV reducer based on comprehensive factor

In practical engineering, there are relatively few fault data on the RV reducer. So according to the principle of reliability allocation, the reliability factor is allocated by the comprehensive factors based on the important factors and complex factors. In most cases, the RV reducer fail due to the failure of some component, therefore, so the whole RV reducer is regarded as one series system. Suppose the reliability of each part of the RV reducer is $R_1, R_2, R_3, \dots, R_n$, The probability of failure of each component is q_i , Then the reliability of RV reducer system is R_s

$R_s = \prod_{i=1}^n R_i$ (1). According to comprehensive reason such as the structural complexity, working condition, importance and maintainability of each component of the RV reducer, the Comprehensive factors are analyzed $q_i = M \bullet w_i$ ($i = 1, 2, 3, \dots, n$) (2). The reliability of RV reducer is as follows:

$R_s = \prod_{i=1}^n (1 - M \bullet w_i)$ (3). M is the proportionality constant, and $M > 0$.

When the overall reliability of the RV reducer needs to be satisfied with R_{ss} , the reliability index of each component is $R_{is} = 1 - \sum_{i=1}^n w_i \bullet M$ (4). The failure rate of whole RV reducer is

$q_s = \sum_{i=1}^n w_i \bullet M$ (5). The failure rate of i th part of the RV reducer is: $q_i = w_i \bullet M = \frac{q_s \bullet w_i}{\sum_{i=1}^n w_i}$ (6)

$C_i = \frac{w_i}{\sum_{i=1}^n w_i}$ (7). C_i - representing the complex factors of the RV reducer $q_i = C_i \bullet q_s$ (8)

$R_i = 1 - C_i \bullet q_s$ ($i = 1, 2, 3, \dots, n$) (9). R_i —the approximate value of the whole reliability index R_{is}

of RV reducer $R_{is} = k \bullet R_i$ (10). $R_{ss} = \prod_{i=1}^n R_{is} = k^n \bullet \prod_{i=1}^n R_i = k^n \bullet R$ (14) $k = \left(\frac{R_{ss}}{R} \right)^{\frac{1}{n}}$ (11),

k —Coefficient of correction $R = \prod_{i=1}^n (1 - C_i q_s)$ (12), $R_{is} = (1 - C_i q_s) \left[\frac{R_{ss}}{\prod_{i=1}^n (1 - C_i q_s)} \right]^{\frac{1}{n}}$

($i = 1, 2, 3, \dots, n$) (13), After calculation: $R_{is} = \left[1 - \frac{w_i}{\sum_{i=1}^n w_i} (1 - R_{ss}) \right] \left\{ \frac{R_{ss}}{\prod_{i=1}^n \left[1 - \frac{w_i}{\sum_{i=1}^n w_i} (1 - R_{ss}) \right]} \right\}^{\frac{1}{n}}$

($i = 1, 2, 3, \dots, n$) (14).

If the overall reliability index of the RV reducer is 0.85, taking full account of the complexity of each subsystem of the RV reducer, according to the number of components that comprise each subsystem, the shape complexity of each part, the difficulty degree in manufacturing and assembly and so on; Combination with the maintainability of each subsystem of the RV reducer, according to the maintenance safety, detection and diagnosis, repair of parts and reduction of maintenance contents, reduce the maintenance skills requirements and other factors; Comprehensive fault analysis of FTA and FMEA of RV reduce. Through the above conditions, the comprehensive factors and distribution reliability indexes of planetary gear, crank shaft, cycloid wheel, rolling bearing, needle tooth, seal

element and other parts were obtained sequentially as shown in Table 6.

Table 6 Comprehensive factor and reliability allocation of RV reducer parts

Component name	Comprehensive factor	Reliability allocation index
Planet gear	0.36	0.9795
Crank shaft	0.25	0.9853
Cycloid wheel	0.40	0.9773
Rolling bearing	0.85	0.9535
needle tooth	0.21	0.9874
Sealing element	0.58	0.9678
other parts	0.18	0.9889

From table 6, the reliability allocation index of each component of RV reducer is closely related to its comprehensive factor, and the higher the comprehensive factor is, the lower the reliability allocation index is. The main reason is that the parts with higher comprehensive factor are prone to failure, and the maintainability, detectability and supportability are poor, so the reliability allocation value is relatively small. If the reliability of the whole machine of RV reducer is improved, it is relatively easy to optimize the parts with lower reliability distribution value, otherwise, the more difficult it is.

4. Conclusion

(1) Combined with the complex mechanical transmission system of RV reducer, a fault analysis model based on FTA and FMEA is proposed. Through the analysis of FTA and FMEA, the main failure mode of RV reducer is obtained, and the theoretical basis for the reliability allocation of RV reducer is also provided.

(2) In case of determining the reliability of the whole machine of RV reducer, based on the analysis of fault mechanism of RV reducer, the various factors that influence reliability of components were integrated, and the comprehensive influence factor of RV reducer parts was determined. From all these, the reliability allocation index of each part was obtained, and a new method and thought for the design of RV reduce was provided.

(3) The reliability allocation method based on fault mechanism has the advantages of strong structure and clear hierarchical thinking, which not only improves the efficiency of distribution, but also makes the distribution result more reasonable. The reliability model established by comprehensive factor reflects the optimization idea of system security, and has a positive effect on the application of reliability allocation theory in system safety engineering.

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