

THE DEVELOPMENT AND PROSPECT OF HYDRAULIC RELIABILITY ENGINEERING

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ABSTRACT

In this article, development and status quo of applications of reliability engineering of hydraulic systems are summarized. Recent research achievements of hydraulic system reliability engineering such as reliability computation, reliability test, reliability analysis, reliability design and software reliability etc, are presented and surveyed. Then prospects and directions of reliability research on hydraulic components and hydraulic systems are put forward tersely according to their particular characteristics.

KEY WORDS

hydraulic system, hydraulic component, reliability engineering, development and prospect

0 INTRODUCTION

Hydraulic system is the important and kernel part of control and power transmission in many great mechanical equipments and systems, and has been used widely such as in astronautics, military affairs, metallurgy, but its faults can bring great losses. Due to historical and some other reasons, reliability of hydraulic components and hydraulic systems is quite bad at large in our country, therefore, to response "Three Campaigns" and the Programs of Mechanical Industry Development brought forward by the former Mechanical Industry Ministry, it is a practical and pressing task to do research on reliability of hydraulic components and hydraulic systems.

Reliability is a performance characteristic that reflects the ability of a system to operate successfully long enough to complete its assigned mission. It reflects synthetically durability, no failure characteristic, maintainability, availability, economical use and some other guidelines of a system or a product. Hydraulic reliability engineering uses reliability theory for reference, combines the characteristics of hydraulic technology, bases on probability theory, mathematical statistics, hydrodynamics and cybernetics, and integrates knowledge of engineering mechanics, tribology, mechanical engineering and system engineering, to

discuss reliability design of hydraulic components and hydraulic systems. The design process of a reliable system is, by nature, iterative. Traditional approaches to the design process of a reliable system follow the requirement determination, preliminary design, analysis, evaluation, and redesign stages until what is regarded as an acceptable design is achieved. The design requirements typically consider reliability, cost, weight, power consumption, physical size, and other system attributes. In today's system design, each design component can be chosen from a group of possible alternatives which have different characteristics such as failure probability, cost, and power consumption. In order to satisfy reliability requirements, redundancy techniques are often used. Error tolerance design based on fault detection and diagnosis (FDD) technique is the last line of defence to ensue high reliability and safety of a system^[1].

Domestic reliability research mainly uses research systems of USA, UK and some other developed nations for reference. It started in 1960s, primarily used in astronautics, aeronautics, nuclear energy and communication technology. In the middle of 1980s, reliability research started to attach importance to mechatronic domain, and reliability research center is first set up in the Mechanical Research Institute of the former Mechanical Industry Ministry. Now, such organizations are set up in many places and have their scheduled activities, which indicates that reliability research work has entered the right way in our country. Reliability research on hydraulic system started at the end of 1970s overseas. In 1981, Hydraulic Component's Reliability was published in U.S.S.R. Domestic reliability research on hydraulic system began a little relatively late. There were mainly hydraulic components' useful life longevity reliability research in HIT, a lot of researches on reliability computation and synthetical reliability analysis of hydraulic components and hydraulic systems in BUAA to aeronautics and astronautics industry, and some theoretic and experimental researches on reliability of valves and hydraulic systems in Shanghai Jiaotong University^[2, 3].

1 STATUS QUO AND DEVELOPMENT OF HYDRAULIC RELIABILITY RESEARCH

Hydraulic system itself is a sort of rigid mechatronic system taking oil as work medium. On the whole, its reliability research belongs to the field of mechanical reliability research. Owing to mechanical reliability research being not long, and mechanical systems being often complicated, having many failure modes, great power, often being single-piece or small-batch products, therefore, to get reliability probability guideline through reliability test according to statistics needs to take a mass of materials and financial resources, even some tests are impossible. In addition, hydraulic system itself has some characteristics such as poor components reliability, few standardization reliability data and complicated structure, which bring some difficulties to study hydraulic system reliability. At present, hydraulic system engineering develops towards high pressure, high velocity, integration, mechatronics and great flow, great power, high efficiency and long life longevity. With the development of micro-electronics technology, the wider use of electrohydraulic servo technology and digital hydraulic system, hydraulic system is becoming more complicated, which bring many new technological problems, so demands on system reliability and no fault rate are becoming higher. Thus hydraulic system reliability research will be developed much rapidly.

In recent years, reliability research in hydraulic domain mainly focuses on the following several aspects:

1.1 Reliability Research and Design on Hydraulic Components

For any hydraulic system, component reliability is the base of system reliability, most components are rigid and precious, complicated in structure, many are produced and designed in single-piece or small-batch, so reliability research on hydraulic components is very important whereas quite difficult.

Now reliability research on hydraulic components mainly has several aspects as follows:

1.1.1 Reliability Analysis and Design on Hydraulic Components Using Fault Tree Analysis (FTA) and Failure Mode Effect and Criticality Analysis (FMECA)

FTA is an effective method for computation the reliability of a system. It provides a mathematical and graphical representation of combinations of events that can lead to system failure. It has long been used for the qualitative and quantitative analysis of the failure modes of critical systems. Double nozzle-baffle-type force-feedback electrohydraulic servovalve is an important component in electrohydraulic servosystem, its reliability design and analysis, reliability model, and reliability

prediction were done in reference [4]. Its series reliability block and reliability model were established firstly, then simplification design and redundancy design were done. FMECA and test were carried through at last, reliability design was verified acceptable and reasonable to meet the design requirement by test. At the same time, theory analysis and test research on electrohydraulic servovalve and electrical magnet in hydraulic valves were completed, which educed many profitable data.

1.1.2 Hydraulic Components Analysis and Design Based on New Theory

Design new-style reliable components based on new design theory such as simplification of complicated structure of hydraulic components, redundancy design, environmental design and man-machine engineering etc instead of old one. Bring forward new design theory to improve old design, for example, design rational oil film using new oil film theory to improve lubricant performance of hydraulic pump friction pair, to enhance the reliability of hydraulic pump greatly, use stress-strength theory to complement traditional method of mean stress plus safety coefficient etc.

1.1.3 Reliability Test for Hydraulic Components

Hydraulic components life longevity test is the base of hydraulic system reliability research, thereafter how to find available, economical and swift test method is an important task. After a lot of researches on hydraulic pump test, we have approximately constituted a complete set of normal test methods on hydraulic components reliability, and it is mature on the whole from test methods to test data processing^[5], but for how to obtain information from reliability acceleration test in relatively short time, because that factors of hydraulic components are relatively complicated, increasing one stress can't discover entirely the failure mechanism of hydraulic components and it is hard to confirm acceleration model and acceleration factor, theoretical result is not all the same as electronic products acceleration test one, now practice is not too mature. Reference [6,7] bring forward two useful methods respectively, and take profitable exploration from theory to practice.

1.2 Reliability Research on Hydraulic System

Like other systems, the whole hydraulic system is mainly taken as the object during hydraulic system reliability research, including reliability prediction and reliability apportionment, reliability analysis, reliability design, reliability test, reliability growth and reliability management etc. The main research directions at present are as follows:

1.2.1 Reliability Prediction on Hydraulic System

System reliability computation is an important parameter to evaluate whether the system is superior or inferior and

whether meets the demand of the task or not, and is an important means to judge or evaluate among systems, is also an important part of system reliability research. There are mainly three methods: (a) To make a precious or semiprecious model of the system, using "Pyramid" model to calculate its reliability from component to system. This method can take full advantage of experiment information at all levels and it is easy to grasp, but complicated computation method, large computation quantity, accumulative error and rather big error especially for low reliability complicated system are its main shortcomings. (b) Simulation method, namely Monte Carlo method. It is to get reliability data through random sample. The total hazard Monte Carlo estimator has been successfully applied to estimate the unreliability of multicomponent systems. Nevertheless, there are some cases where it is less efficient than the crude estimator. A simple modification that improves the performance of the total hazard estimator is proposed in [8]. (c) Bound method. It is mainly used in big and complicated system's reliability prediction. It is not yet mature for big system and small subsample complicated system due to its relatively hard mathematical processing of reliability synthesis. Traditional reliability prediction bases on separate component failure rate and estimates component reliability by exponent model. This method can mislead to "repaired is new", it would lead to rather big error for mechanical and hydraulic system's reliability prediction. So one of main research directions at present is to develop new reliability prediction model.

1.2.2 Reliability Analysis on Hydraulic System

Reliability information, fault modes and transmission relations of faults in hydraulic system etc., which are educed by reliability analysis, can help to understand hydraulic system interior structure further and offer plenty of conveniences and criteria to design, management and fault diagnosis of hydraulic systems. At present, there are two common methods, FTA and FMECA^[9]. These two methods whose characteristics are concise directions try to set up vivid regulations, then go through fault analysis and fault reasoning. They are adopted to analyze hydraulic systems in quite a few literatures at the present time. But their shortcomings are as follows: (a) It is quite complicated and trivial to set up fault tree. Moreover, it is error-prone, especially for big and complicated system's control loop. Now in quite a few literatures some researches are carried out and bring forward some valuable methods to deal with control system's fault tree, such as directed graph method. Furthermore, computer aided establishing fault tree has been explored further in some literatures, but there are not any quite mature and perfect methods yet; (b) FTA's complicated processing and much time cost lead to some difficulties in on-line application. On-line FTA needs to find corresponding test rapidly, according to which to

distinguish failure components. There are quite a few literatures raising several methods of on-line FTA and automatic analysis. At the same time, they are all suitable to a certain type system. But the method suitable at large to all kind of systems, especially to hydraulic systems has not appeared in literatures; (c) The fuzziness of hydraulic systems is encumbrance to precious mathematical processing. Because that characteristics and causes of hydraulic system's fault are both fuzzy, e.g. the same fault induced by different causes, the same cause resulting in different faults and more complicated fault characteristics while several faults concur, so exactitude and digitalization processing methods is very difficult and not precise. Therefore, reasoning course of digitalized model inference based on FTA & FMECA is quite difficult. Now fuzzy mathematics is introduced to reliability research by quite a few people, and fuzzy processing and reasoning are introduced to hydraulic machines, fuzzy identification and fuzzy synthetic judge are also introduced to hydraulic system's fault. The data at all conditions are standardized and defined as fuzzy equivalence matrix and similar matrix, then judge the most possible subset to happen according to each λ -cut matrix. Fuzzy mathematics has greatly improved application range and precision of FTA & FMECA^[10].

1.2.3 Reliability Design for Hydraulic System

Reliability design is the most important step in reliability engineering, and that "reliability comes from design" is recognized now. System designed reliability is the upper limit of system reliability. Therefore, it is very significant to raise system reliability during design. There are many reliability design methods in mechanical systems, for hydraulic system's design, it is mainly to adopt redundancy design and derating design to raise the whole machine's reliability, as well as that new hydraulic circuit and new realization methods substitute old ones to raise system's reliability. The former one is mainly used in more crucial system to ensure system's mission reliability, which is used far and wide in astronautics, and is very effective to raise reliability of hydraulic system. Expensive to realize and to make system control model complicated are its shortcomings, besides it has a certain limit to raise system's reliability. Furthermore, there are some researches on the selection of remaining number, setting up of the model and confirmation of signal detection threshold value in some literatures, such as computer aided synthetical design of airplane control system in BUAA etc. In addition, some control types or oil circuit realizations of hydraulic systems are not so good or already aging, which effects system reliability greatly, whereas adopting new realization type to improve or substitute customary hydraulic transmission or control circuit is a common and economical method, such as adopting logical cartridge valve to renovate water press transmission and control circuit^[11,12].

1.2.4 Reliability Management for Hydraulic System

Hydraulic system requests that manipulators have certain speciality knowledge and can manipulate and maintain the hydraulic system reasonably. Hydraulic system's distinct feature is that its work medium is oil and there are many little damp orifices and clearance flow, once the oil is contaminated, it would accelerate component's abrasion and lead to component's jam and even failure. So hydraulic oil contamination is a primary factor of hydraulic system's fault. Doctor Robinowicz of MIT found out that 70% of hydraulic system faults are caused by hydraulic oil's contamination. Contamination is mainly caused by contamination outside and inside of the system, oxidation and deterioration of oil itself. So it is a very important step of raising hydraulic system's reliability to control oil contamination. There are some literatures on how to control hydraulic system oil contamination during its design and operation. There are some other articles researching on the monitoring of oil contamination and oil sieving equipment.

For other aspects of reliability research on hydraulic system such as reliability growth, reliability apportionment, reliability simulation etc., these are the same as other systems at large, so we don't recount it detailedly.

2 PROSPECT OF RELIABILITY RESEARCH ON HYDRAULIC SYSTEM

With the intermingle of computer technology and fuzzy theory in every subject, reliability research on hydraulic system will develop more rapidly and greatly, the hotspots and directions of reliability research on hydraulic system can safely be predicted as following several aspects:

2.1 Reliability Analysis on Combination of FMECA and FTA for the Hydraulic System

FMECA and FTA are two kinds of typical methods used for analyzing causality of the system's failure. While analyzing the complex system, they are limited for their tremendous workload. On the other hand, both FMECA and FTA have their disadvantages. For example, FMECA isn't very direct for the description of system's reliability and safety and its capacity for quantitative analysis isn't powerful, while FTA can not demonstrate the system's reliability information as comprehensively as FMECA. Therefore how to reduce FMECA and FTA's workload and utilize their advantages are the main problems to be solved. In addition, how to use FMECA and FTA to analyze the reliability of hardware and

software synthetic system is the another question worth being researched, the computer-aided combination technique of FMECA and FTA which has been explored in BUAA is a new direction in the hydraulic system reliability research recently. The same research on huge mechanical product is done in reference [13], which would be used for reference to hydraulic systems and hydraulic components.

2.2 Computer Aided Synthetical Reliability Analysis

A manual generation of fault tree (FT) is a tedious, time-consuming and error-prone task. To create an FT, the system must be modeled by suitable representation, because no FT generation method can extract more information than that contained in the model. An FT expert would use heuristic to locally analyze an upper level event in terms of lower level events. So automated FT generation approach is promising and studied in reference [14]. The primary computer-aided reasoning approaches to performing the FMECA are numerical simulation, expert system(ES) and causal reasoning. An approach based on a knowledge database is presented in reference [15]. Combining reliability research and system fault detection and diagnosis and taking advantage of computer's quick computation, expert system is set up in fault detection and failure analysis to raise the efficiency of fault detection. There is great progress in computer aided synthetical reliability analysis for electronic products nowadays, while computation methods of computer aided establishing tree for hydraulic system's fault tree and computer aided analysis are becoming hotspots. How to deepen reasoning for fault tree, to manage data neatly and to find the minimum cutset and minimum pathset is the key.

2.3 To Establish System of Reliability Engineering

Combine reliability technology with maintainability and supportability, unite management, engineering and technology as a whole and take synthetically system reliability, performance, cost and some other factors into account. From the most basic and economical design, inherit probative effective technology, e.g. outline comment and examination, derating design, FMECA & FTA, security analysis, life longevity and reserve reliability, maintainability design and analysis, reliability growth test, analysis and mending, information system and failure reports, analysis and corrective action system etc. Besides adopt actively some international advanced technologies, such as robust design, critical item failure mechanism and failure analysis, R & M test technology, integrated logistic support engineering, maintainability expert system etc. Use American Concurrent

Engineering, European Dependability Technology and Total Quality Management in Japan for reference, pay attention to practicability of reliability engineering, to make reliability technology more practical. Otherwise, reinforce the relation among production, education and research, establish reliability data net, therefore set up and consummate reliability system engineering sprouted in the early part of 1990s in China, to make it accord with domestic situations.

2.4 Fuzzy Reliability Theory

Classical reliability theory bases on two basic hypotheses: probability hypothesis and binary-state hypothesis. In some conditions, binary-state hypothesis is untenable and should be substituted fuzzy-state. For small sample questions, possibility hypothesis is adopted instead of probability hypothesis. Profust reliability theory brought forward by Prof. Cai Kaiyuan in BUAA based on probability hypothesis and fuzzy-state hypothesis, posbist reliability theory on possibility hypothesis and binary-state hypothesis and posfust reliability theory on possibility and fuzzy-state hypothesis are called by a joint name as fuzzy reliability theory. While classical reliability theory is also called probist reliability theory. Fuzzy reliability is inheritance and development of classical reliability, now, there are some applications in hydraulic reliability at a certain extent, but most of them are at fuzzy synthetical judge phase, especially research on fuzzy reliability in hydraulic system is not common and mature. Fuzzy mathematics presents the quantitative representation of fuzzy notions, fuzzy relation, fuzzy matrix and some other algorithm, fuzzy probability is also set up based on this, which provide wide condition for fuzzy reliability. It can be safely predicted that how to apply fuzzy logical judge to hydraulic reliability would be an important direction and will make difference it combines synthetical reliability analysis.

2.5 Software Reliability Research on Hydraulic System

The higher automatization degree of hydraulic system, the more complicated and important its software would be, the bigger development of software reliability research on hydraulic system must be. Due to rather big difference between software reliability and hardware reliability, the former fault is "locked-in", sensitive to environment and logical generally, so there are much more difficulties in researching software reliability. There is no not only simple but widely used software model yet, there is not a little progress in the theory of software reliability research in our country, but in engineering practice we lag developed nations a lot^[16]. For hydraulic system software, it is not different in essence from other system software reliability, we can

use it for reference, combine the characteristics of hydraulic systems to develop software reliability analysis theory which can be applied to hydraulic engineering practices. Modern hydraulic system is composed of software and hardware, therefore, the synthetic reliability analysis on software and hardware system is new research direction.

3 CONCLUSION

Implanting reliability technology of mechanical and electronic equipments into hydraulic domain will inspire the development of hydraulic reliability engineering. While hydraulic technique is developed well in the domain of military affairs, with the development of integration of economy and multipolarization of the world, to conform the need of knowledge economy, to develop civil hydraulic technology, to make the setting sun industry blooming, and to improve the level hydraulic technology are tidal currents. Hydraulic technology and hydraulic reliability engineering are coming and promising in the effects of hydraulic craft-brothers.

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