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Degradation assessment and life prediction of electro-hydraulic servo valve under erosion wear

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ABSTRACT

This paper presents a degradation assessment and life prediction method for electro-hydraulic servo valve (EHSV). Unlike traditional statistical methods, our work is motivated by the failure mechanism of erosion wear. The degradation of performance characteristic was related with structure wear in twin flapper–nozzle valve and spool valve. Mathematic models of turbulent and erosion wear were established by the combined technologies of computational fluid dynamics and erosion theory. By visual simulation, we analyzed the erosion wear distribution and erosion wear rate under different contaminated oil conditions and working missions. Furthermore, degradation models of performance characteristic were built according to degradation trends of system performance under different erosive wear stages. Finally, the assessment results show that: (1) Hydraulic oil with contaminant particles will distinctly erode the sharp edges of valve bushing and spool. Besides, the erosion rate depends on valve structure and port opening size. (2) Wear at sharp edges of spool valve influences pressure gain, null leakage flow and lap. Furthermore, these performance indicators are monotonically degraded. With the definition of failure for the EHSV, the service life is 9000 missions by our simple mission profile.

1. Introduction

1.1. Objective

Electro-hydraulic servo valve (EHSV) is a typical precision hydraulic component widely used in aviation aircraft. Engineering experience shows the reliability and life of the EHSV are vulnerable to external environmental factors, such as contamination particles in hydraulic oil. Failure mechanisms of EHSV are highly associated with hydraulic condition. Some researches show that contamination particles in hydraulic oil often wash out the edges of valve components [1]. This will decrease service life and result in performance degradation simultaneously. The failure of the servo valve caused by contamination particles mainly includes the increase of internal leakage flow, input current hysteresis and null leakage, the decrease of input current threshold, pressure gain and gain linearity [2].

Now, the technology for assessing performance degradation subjected to contaminated oil and predicting service life is becoming a burning demand for servo valve engineers, especially in the design stage of these servo valves. Therefore, the research effort described in this paper focuses on performance degradation subjected to erosion wear. To assess the degradation, it is necessary to understand which structures or components have experienced wear, the predominant aging

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mechanisms and their effects, and the physical manifestations of degradation. With this information, we develop the technical basis for the structural wear assessment and performance degradation prediction.

The approach adopted in this research project consists of two phases. The Phase I includes identifying the potential erosion location, predicting the erosion rate and assessing the structural degradation. Phase II consists of assessing the effects of structural degradation, forecasting performance degradation, calculating accumulated wear of mission profile and predicting the service life. The logistic relationship between the two parts is displayed in Fig. 1. Besides, it exhibits the researching content and purpose of each part.

1.2. Background

The theory of degradation assessment and life prediction is the key foundation of safety service of the machine parts and equipment. With the development of the past century, several scientific branches, such as life prediction theories based on mechanics, probability statistics and artificial intelligence technique, are founded through researches on the aircraft, ship, vehicle, and other major mechanical major equipment [3]. Now, degradation assessment and life prediction are widely used for machinery equipment in various engineering fields. However, most of these researches are just proceeded for various materials or various parts of the machinery equipment. Besides, our investigation shows the current theory of degradation assessment and life prediction is not suitable to forecast the performance degradation of the EHSV. First, the main reason of performance degradation is structural wear. So far, degradation assessment methods based on mechanics and probability statistics are mainly used for stress-based fatigue. Simultaneously artificial intelligence technique greatly depends on the field performance data and could not settle degradation prediction of system performance in the design stage of the product.

Actually, for reliability research of the EHSV, most researchers now focus on fault diagnosis technologies [4]. The fuzzy comprehensive evaluation is proposed to optimize the failure modes, effect and criticality analysis (FMECA) of the EHSV [5]. While during the durability analysis and life prediction fields, many physical experiments are conducted to assess the life and reliability of hydraulic components. Fitch and Hong investigate the testing of the fluid contaminant wear for hydraulic components and proposes a method for predicting the service life [6]. An engineering theory on the contaminant wear and test method is presented by Jia [7]. Obviously, at present, the study of the EHSV reliability is mainly dependent on the physical testing. However, for lack of real product, there are few practicable methods to predict the service life for products in the development stage. This paper focuses on performance degradation issues of the EHSV caused by contaminated oil. So the probable erosion location and erosion rates are really challenging to explore. Actually, structural wear could be predicted by computational fluid dynamic (CFD) techniques [8–10]. By comparing the ability of currently CFD-based modeling tools to predict erosion conditions, the fluid flow processes are generally predicted well for both the simple and complex geometry [11].

For erosion prediction, a well-established three-stage process exists: (i) flow field prediction using viscous or inviscid models, (ii) particle trajectory calculation by modeling the discrete particle dynamics and (iii) determination of erosion wear using a material removal model. The three elements of the CFD-based model are implemented in general CFD codes, such as Fluent, Phoenics, Star-CD, and CFX (four of the main commercial softwares). The development of fluid particle flows model is well documented and will not be discussed in detail here. However, the erosion modeling aspects will be discussed in some detail. For erosion wear of structure material, many kinds of wear formulae or models are proposed. In the early stage, most scholars primarily investigate the essential of erosion mechanism. Finnie presents that erosion mechanism is micro-cutting and publishes an analytical erosion model used to predict erosion rates for ductile material [12]. Tilly proposes the two-stage erosion process, i.e. the micro-cutting and surface fragmentation [13]. In recent years, many scholars explore wear model using experimental data and wear mechanism. Researchers mainly focus on particle impact speed and angle, material

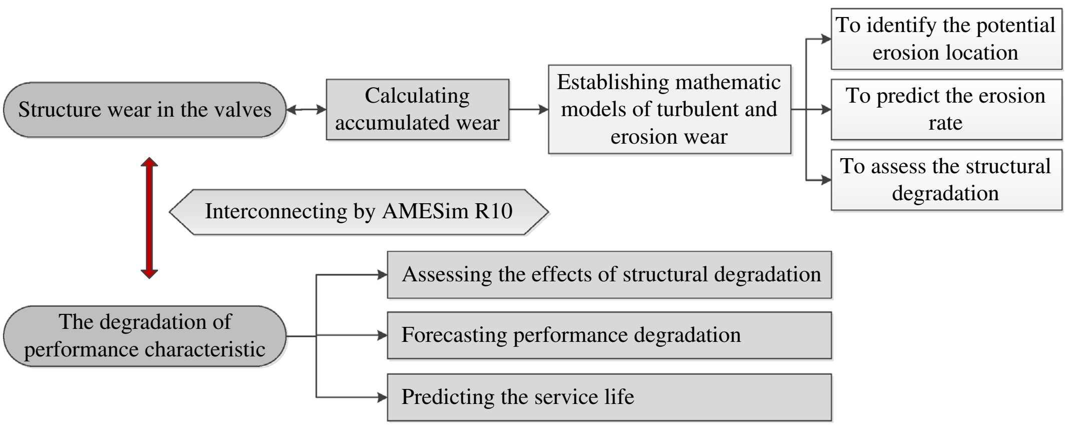

Fig. 1. The technology roadmap for degradation assessment.