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Simulation of Ageing of Aircraft

In today's world, there is increasing demand of new technologies. As the world is growing, new technologies are emerging. To sustain the new technologies, technologies used for its maintenance must be developed. In the aviation industry with respect to the Industry 4.0 system, its maintenance strategies are also developing. The aim to this study is to present a mathematical model which is used to predict the ageing of any technical system. The authors used the Markov process theory to model the ageing process. As per the model, results and future work are determined and discussed briefly.

Keywords: *maintenance, ageing process, aviation, mathematical model, Markov process*

1. Introduction

In the aviation industry, predictive maintenance strategies become more advanced day by day. Predictive maintenance is planned to observe the working condition of maintained equipment and to forecast maintenance requirements. Ageing can lead to damage and to avoid this problem, it should be modelled. With the prediction of the remaining useful life, data of condition monitoring becomes valuable for planning of optimal maintenance. Change of the system's behaviour as per its current approximated reliability and its predicted remaining life is the biggest challenge when it comes to forecast the condition management. These strategic management methods are commonly consisting of how to avoid sudden failure and how to improve the reliability which is highly important for aerospace industries. The role of maintenance in Industry 4.0 is rapidly increasing to prevent failures.

With the help of alarm-based maintenance framework, a remaining useful life prognostics strategy which works on predictive maintenance is presented by Ingeborg de Pater et al. [1]. Maren David Dangut et al. [4] studied hybrid machine learning approach to predict the aircraft component failure with better accuracy. Maintenance modelling and a maintenance planning decision support system is briefly studied and presented by Mohamad Danish Anis [2].

Authors study the Industry 4.0 approach maintenance strategies in aviation industry. Their aim to develop a new Markov process-based mathematical modelling methodology which can be used to predict the ageing processes of technical systems.

The rest of the paper is organised as follows: Section 2 shows the aircraft maintenance methods and process. Section 3 presents the proposed Markov model of ageing process. In Section 4 results of the proposed Markov model are discussed briefly. In the closing part of the paper the proposed future framework is presented.

2. Aircraft maintenance

For many decades, the aviation industry has been developing very rapidly. The development of new technologies poses an even greater challenge to its durability. To sustain its high impact efficiency, maintenance is the basic and most important factor. New technologies are evolving day by day and hence maintenance strategies need to evolve with respect to time to overcome the upcoming challenges. We present this study in the light of this perspective.

Aircraft maintenance is a well advanced system to maintain and repair aircraft and to make schedules of maintenance, under the skilled and authorised organisation of the Federal Aviation Administration (FAA) and the Continuous Airworthiness Maintenance Program (CAMP) to prevent any type of failure considering safety measurements. Every machine system is sensitive to its operating condition. When operating condition is well taken care of then it gives best results towards its work efficiency.

Now we are focusing on maintenance management and their techniques which helps to estimate the functional life of any system. If maintenance is ignored, it can result in huge loss and sudden failure can occur. With the help of prediction modelling, maintenance can be described and scheduled.

Liwei Zhou et al. studied the life cycle cost of a convertor transformer. They improved the cost of failure losses, failure rate and economic losses with the help of maintenance decision optimisation method. After maintenance, the failure rates of equipment decrease. The Weibull distribution method is used to make failure rate curve. A flow chart is made and the smallest Life-Cycle Cost (LCC) is selected as best maintenance strategy. The practical situation and presented model show improvement in the calculation method of failure loss cost [3].

Velásquez et al. suggested the reliability model based on maintenance data using both classical and Bayesian methodologies. With the help of classical approach, it uses both life test and design of experimental technologies. Three main costs are evaluated which are investment cost, maintenance cost and failure cost. Their presented data driven framework helps to determine the critical maintenance factors [4].

A hybrid machine learning method is presented by Dangut et al. [5] that uses different language processing techniques for preventing unpredicted equipment failure and advances its service quality. The main objective is to determine a suitable work plan for component replacement due to unexpected maintenance with the help of time series, log base and limited failure data. Unplanned maintenance can be reduced using the suggested robust prognostic model. This presented model can alert any component replacement within defined space. Moreover, this model can forecast 50% of its unplanned aircraft component failure.

Dangut et al. presented an algorithm which converts the unusual failure prediction issue into a consequent decision-making process. The important objective of this study is to monitor the effectiveness of this system and predict component failure with low false positive rates. The problem was classified as a Markov decision-making process and resolved by connecting support learning with deep neural networks. The result concluded that the method of deep reinforcement learning for highly rare failure prediction is more viable. It means that the unplanned maintenance can be minimised with low cost of maintenance techniques [6].

Erosion and corrosion are the main factors which affect the ageing of systems. The properties of materials are to be taken into consideration as per their application, which can be planned with the help of simulation predictive maintenance.

Kolawole et al. presented modelling studies of action of corrosion and erosion on low carbon steel with different pH level. Corrosion pits are explored by SEM. FEM analysis is done for pit geometry of corrosion. Fatigue tests are done. Images and FEM analysis shows that corrosion cracks are created by cyclic stress. Corrosion pits can further grow when driving forces are exceeded. A regression model can be used to predict the effect of different pH which leads to fatigue rate [7].

Shard et al. examined carbon-fabricated composite structure using dry sliding method. Wear test is done. Simulation and analysis on ANSYS workbench are done. As the carbon fibre content increases, hardness along with wear resistance increases, too. It was observed that the value of the coefficient of friction for carbon fibre is very high and stable as compared to polyetherimide composite material in dry sliding condition [8].

Zuo et al. studied the effects of chrome on corrosion behaviour of steel spring. Optical microscope is used to observe the corrosion morphology. Laser scanning, confocal microscopy and scanning electron microscopy and three-dimensional simulation are carried out. Corrosion products are qualitatively and quantitatively analysed by using X-Ray. Chrome is beneficial for corrosion resistance. The higher the chrome content, the higher the corrosion resistance [9].

Stadnicka et al. proposed a mathematical model for developing aircraft maintenance considering lead time taken by proficient operators. This model is very useful in case of a moderate number of capability. Many companies need to reduce repair times to stay competitive. To cut the extra time and to make a time-effective maintenance schedule, a mathematical programming model is developed to manage the operations and help to make the decision effectively [10].

The Aircraft Environmental Control System (AECS) is a very important factor in its operating condition. Damage or low performance of AECS can lead to failure. For this reason, performance check is very important. In accordance with performance check Cheng et al. proposed a classified plan which works by visual cognition theory. The error is transformed into image to know every possible detail with the help of different technologies. The complete degradation process can be evaluated with this process. The AECS simulation model made from MATLAB Simulink gives the simulation data. As a result, these simulation data are very effective to evaluate the degradation process [11].

The Structural Health Monitoring (SHM) of aircraft is briefly elaborated by Pant et al. [12]. While utilising condition based monitoring, for the monitoring of the operation and damage, SHM is a key factor. Aircraft maintenance with low cost, more accuracy and less time can be achieved by SHM technique. SHM can also be defined as "Non-destructive inspection process". A robust model on probability of detection methodology can reduce the cost and this needs to improve in other aspects, too to get the more benefit of structural health monitoring.

Nowadays, new approaches with a growing aim for maintenance process which is widely utilized in the world of Industry 4.0 is briefly presented by Di Nardo [13]. The use of Industry 4.0 in connection with manufacturing and maintenance management is reviewed.

3. The Markov model of ageing process

Maintenance is a process which needs to be executed on time to reduce the chances of sudden failure and to increase its efficiency, whereas ageing is the process in which structural and functional changes occur in a mannered time. For this, the proposed model illustrates mathematically a discrete time–discrete state Markov-model. In this proposed Markov model the given objectives were detailed:

a) the general parameter η can only increase during examined time interval;
b) during the initial time-step approach, the general parameter η can only be increased by one or two parameters of value-step with β_1 and β_2 probabilities, where:

$$\beta_1 = 0.011 \quad (1);$$

$$\beta_2 = 0.001 \quad (2);$$

c) the above evaluated values of probabilities do not change which is dependent on time;
d) the general parameter η has more than one initial value, which have normal distributions.

Using the above discussed clarifies that the probability of parameter η does not increase:

$$\beta = 1 - (\beta_1 + \beta_2) \quad (3)$$

The mathematical model of the process that determines changes of probabilities during one unit of time – form i^{th} to $i{+}1^{th}$, is given as:

$$\mathbf{p}(t_{i+1}) = \mathbf{B} \cdot \mathbf{p}(t_i) \quad (4)$$

The Markov matrix **B** of the suggested Markov model (4) has the specified format, which is:

$$\mathbf{B} = \begin{bmatrix} \beta & 0 & 0 & \cdots & \cdots & 0 \\ \beta_1 & \beta & 0 & \cdots & \cdots & 0 \\ \beta_2 & \beta_1 & \ddots & & & 0 \\ 0 & \beta_2 & & \ddots & & 0 \\ . & . & & & . & \\ 0 & 0 & \cdots & \cdots & \cdots & \beta \end{bmatrix} \quad (5)$$

Figure 1 illustrates the probability density functions $f(\eta)$ of the investigated general parameter η.

The next approach is the minimum and maximum values where the general parameter η was investigated. To determine the minimum and maximum values,

$$\varepsilon = 10^{-3} \quad (6)$$

Starting parameters were used as minimum probability values.

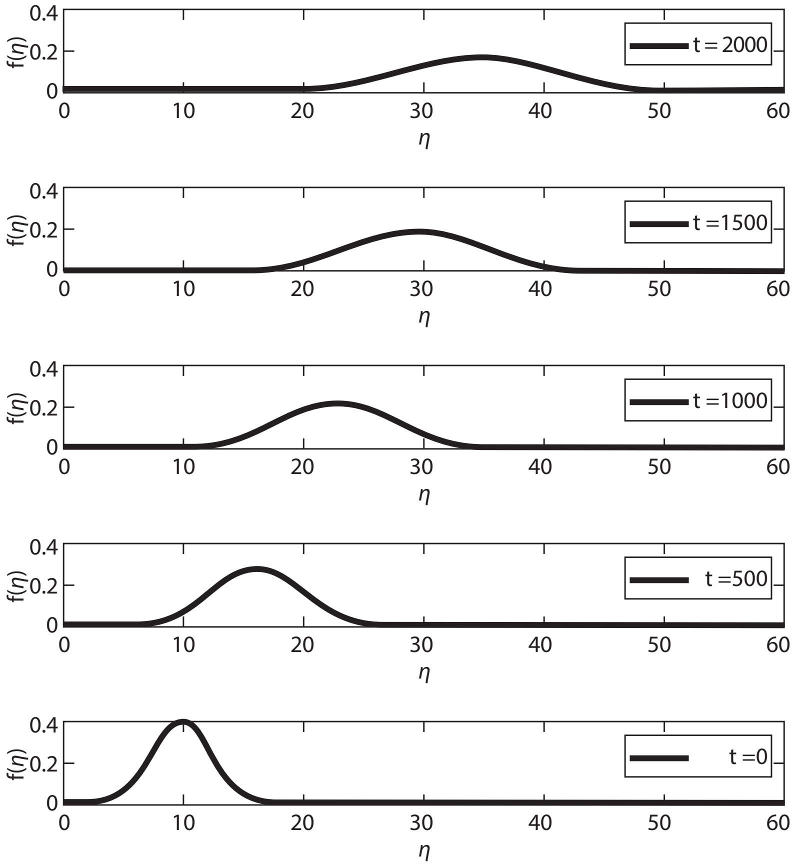

Figure 1
Probability densities of general parameter η at different times

Figure 2 shows the maximum and minimum values of general parameter η.

4. Result and discussion

As we studied maintenance management which is an important factor in the ageing of systems, maintenance has the key role to manage the life of components or whole system. The discussed articles show maintenance methods and their results from which we can predict the life. Samples were tested and with different suitable methods, data are collected as per their application and after the analysis mathematical models and frameworks are presented to determine the required factors.

This particular study shows a proposed model to characterise a general ageing process. This proposed model is the “second step” of our work based on a methodology of investigation and forecasting of ageing of real technical systems.

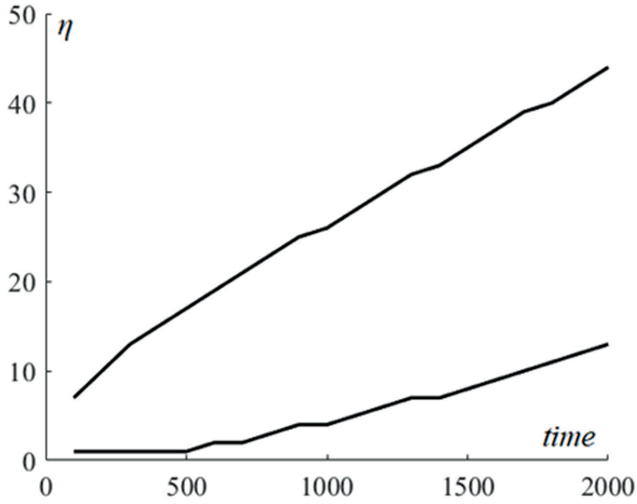

Figure 2
Maximum and minimum values of parameter η

The following conclusions can be obtained from the above results:

1. the proposed method can be useful to model the ageing processes
2. the results of model-based simulation can be used to predict the remaining useful life and to evaluate ideal maintenance schedules
3. the developed Markov model is suitable for further improvements reducing repair time and value steps

5. Future framework

The future work and necessary modifications of this model to obtain their optimal solutions are the followings:

1. the technical parameters can be increased and decreased randomly during modelling in framed time interval which should be represented mathematically;
2. for modelling of the ageing processes, the Markov-matrix B should be determined and it should be dependent on time;
3. the changeability of the ageing processes can be modelled by using the Monte Carlo simulation method;
4. the studied ageing model should be developed multi-dimensionally.

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A repülőgép elhasználódási folyamatának szimulációja

Napjainkban egyre nagyobb az igény az új technológiák iránt. Ahogy a világ fejlődik, úgy jelennek meg új technológiák. Az új technológiák fenntartása érdekében a karbantartásukra használt módszereket is fejleszteni szükséges. A légiközlekedési ágazatban az Ipar 4.0 rendszer tekintetében a karbantartási stratégiák is fejlődnek. A tanulmány célja egy olyan matematikai modell bemutatása, amely a technikai rendszerek elhasználódásának, károsodásának előre jelzésére szolgál. A szerzők a Markov-folyamatok elméletét alkalmazzák az öregedési folyamat modellezésére. A szerzők az eddigi modelleredményeket mutatják be és a jövőbeli munkát határozzák meg.

Kulcsszavak: *karbantartás, öregedési folyamat, légi közlekedés, matematikai modell, Markov-folyamat*

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