Normal Condition Model for Mechanical Prognostics based on grey model

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Submission date: 26-Jul-2018 12:31PM (UTC+0700)
Submission ID: 985336474
File name: ndition_Model_for_Mechanical_Prognostics_based_on_grey_model.pdf (1.04M)
Word count: 2158
Character count: 12478

Proceedings
The 2nd International Multidisciplinary Conference 2016
November 15th, 2016, Universitas Muhammadiyah Jakarta, Indonesia
Stenly Tangkuman & Jotje Rantung, Normal condition model for mechanical prognostics based on grey model : 432-439
ISBN 978-602-17688-9-1

NORMAL CONDITION MODEL FOR MECHANICAL PROGNOSTICS BASED ON GREY MODEL

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Abstract

Prognostics is a process of predicting the future conditions of a product based on an assessment of its current state-of-health and its past performance conditions. Actually, in previous research, the prognostics consists of three steps; namely building normal condition model, estimating degradation state, and predicting future condition as well as assessing remaining useful life of the machine. At the first step, the prognostics method has to identify whether a system or a machine is in good condition or not based on current condition. In other words, a normal condition model must be build first. This paper has been proposed two techniques according to the approach of normal condition modeling. These techniques may support developing of a prognostics method based on grey model. Result shows that prediction performance of both techniques is satisfying by root-mean square error (RMSE) and linear correlation (R) values. Although there is little different in result among the proposed methods, experiment and other research, the prediction performance is enough satisfying. However, using the both approach in a prognostics application may give the best result. For validating the proposed method, data from low methane compressor used in petrochemical industry was employ. The data contains information of machine history with respect to time sequence.

Keywords: *condition monitoring, grey prediction model, normal condition model, prognostics*

INTRODUCTION

Being able to perform precise and reliable prognostics is the key of condition based maintenance for an engineering system, and it is also critical for improving safety, planning missions, scheduling maintenance, reducing maintenance costs, and down time. Prognostics is an ability to predict the remaining lifetime, future health states, or reliability of machinery based on current health assessment and historical trends. Thus, there are two main functions of prognostics: failure prediction and remaining lifetime estimation (Tangkuman 2014). A simple ilustration about the mechanical prognostics is shown in Figure 1.

Condition monitoring data can provide information on current working age and state of the system that may affect its future life. This information then can be used for prediction of future condition and remaining useful life of the machine or components. Prognostics deals with machine health condition based on measured data from condition monitoring (Widodo 2011). Actually, failure prediction allows the pending failures to be identified before they come to a serious situation.

The existing prognostics methods can be classified into three categories, which are physics model-based prognostics, knowledge-based prognostics, and data driven prognostics (Peng 2010). Among the data driven approaches, the grey model which have been successfully used in other domains before, has been introduced to deal with machine fault prognostics.

Previous research has achived a new mechanical prognostics method based on grey model (Tangkuman 2012). The method consists of three steps; namely building normal condition model, estimating degradation state, and predicting future condition as well as assessing remaining useful life of the machine. At the first step, the prognostics method has to identify whether a system or a machine is in good condition or not based on current condition. In other words, a normal condition model must be build first.

This paper has been proposed two techniques according to the approach of normal condition modeling. These techniques may support developing of a prognostics method based on grey model. However, the advantages and disadvantages of the techniques will be discussed.

The remaining parts of this paper are organized as follows. In Section 2, this section depicts two techniques for building normal condition model. After that, the model was employed for predicting future conditions. Discussion about these tehcniques was done in Section 3. Finally, the conclusions are presented in Section 4.

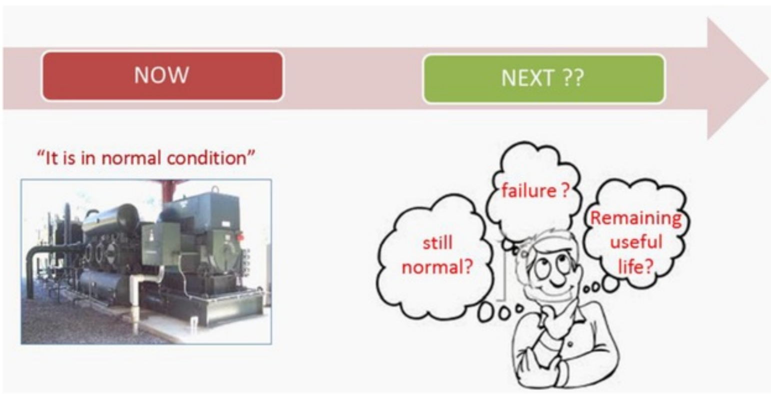

Figure 1. A simple ilustration about the mechanical prognostics

Grey Prediction Model

The steps used in the grey prediction model are shown in Figure 2. AGO means the accumulated generating operation, and IAGO means the inverse accumulated generating operation. On the other hand, $X^{(0)}$ represents the original data series, and $X^{(1)}$ represents the AGO series (Gu 2010, 436)..

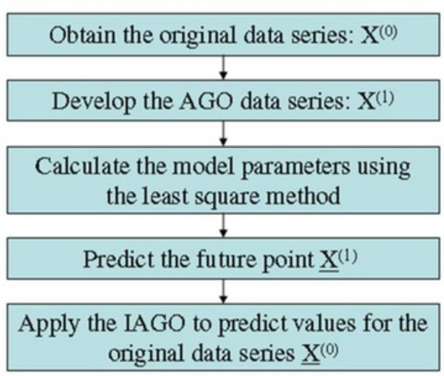

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Figure 2. Grey Prediction Procedure

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Proposed Model

Previous study has proposed a new mechanical prognostics method based on grey model (Tangkuman 2012). The method consists of three steps; namely building normal condition model, estimating degradation state, and predicting future condition as well as assessing remaining useful life of the machine. This paper discusses the three steps generally, and discusses the first step specifically.

Normal condition model means that the model has to identify whether a system or a machine is in good condition or not based on current condition. Therefore, a normal condition model must be build first. For building the normal condition model, this work discusses two techniques; namely constant limits (technique 1) and 4th degree polynomial (technique 2). Application of these techniques is depicted in the next section.

For validating the proposed method, data from low methane compressor used in petrochemical industry was employ. The data contains information of machine history with respect to time sequence. It is root mean square feature extracted from vibration signal.

Technique 1: using constant limits for normal condition model

The first step of the mechanical prognostics method is to build a normal condition model and calculate the error indicator. The model was built based on the first 200 data, from time of 1 to 200. Certainly, in this period of time the machine was found in normal condition.

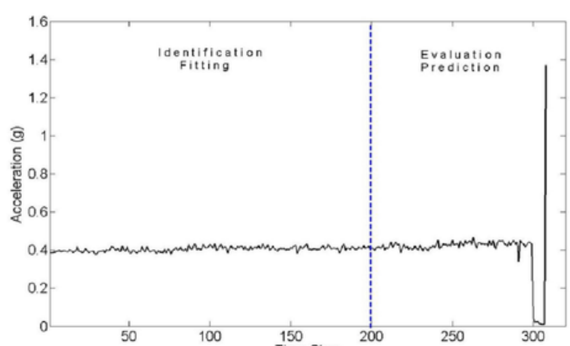
The splitting of the condition monitoring data could be seen in Figure 3. Hereafter, the limits of normal condition model were taken at acceleration values of 0.4 ± 0.039 as shown in Figure 4. On the other hand, error indicator based on tehcnique 1 was shown in Figure 6.

The result of the second and the third step was shown in Figure 8. The prediction result indicates that the incipient failure occurs at time of 291 and the final failure occurs at time of 308. Finally, based on the formula, remaining useful life of the machine in this case is 102 hours.

Technique 2: using 4th degree polynomial for normal condition model

The difference between technique 1 and technique 2 is at the first step approach. In technique 1, the normal condition model was built using constant limits of values. On the other hand, for technique 2 the normal condition model was built using polynomial of 4th degree. Figure 5 describes the normal condition model using technique 2, and Figure 7 depicts error indicator curve using technique 2.

Based on the previous result, actual and prediction of survival probability can be achieved as shown in Figure 9. The incipient and final failure thresholds in this case are also at survival probability of 0.9 and 0.1 respectively. The prediction result indicates that the incipient failure occurs at time of 284 and the final failure occurs at time of 308. Finally, by technique 2 the remaining useful life is 144 hours, ((308 - 284) x 6).



Fiqure 3. Splitting of Data for Building the Normal Condition Model

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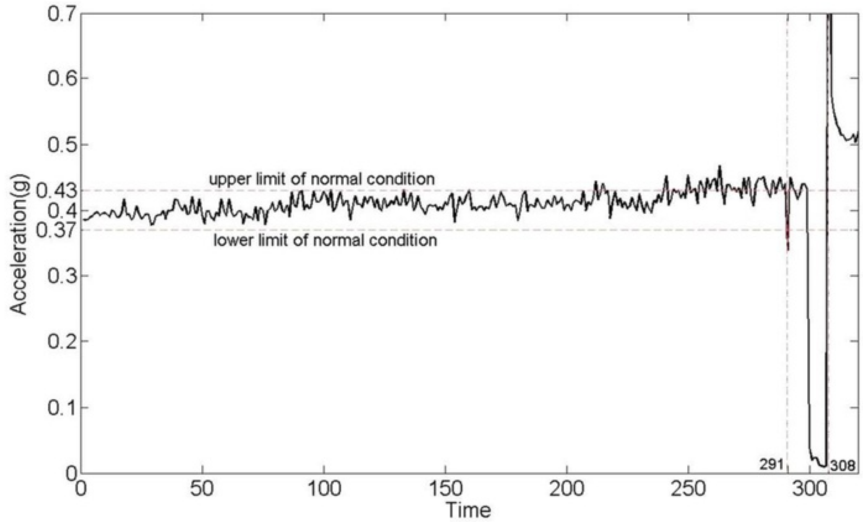

Figure 4. Normal Condition Model (Technique 1)

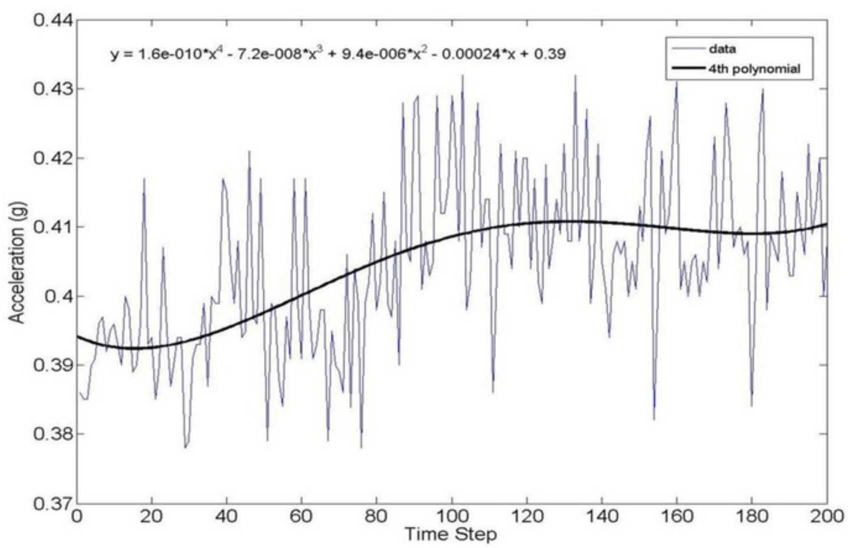

Figure 5. Normal Condition Model (Tecnique 2)

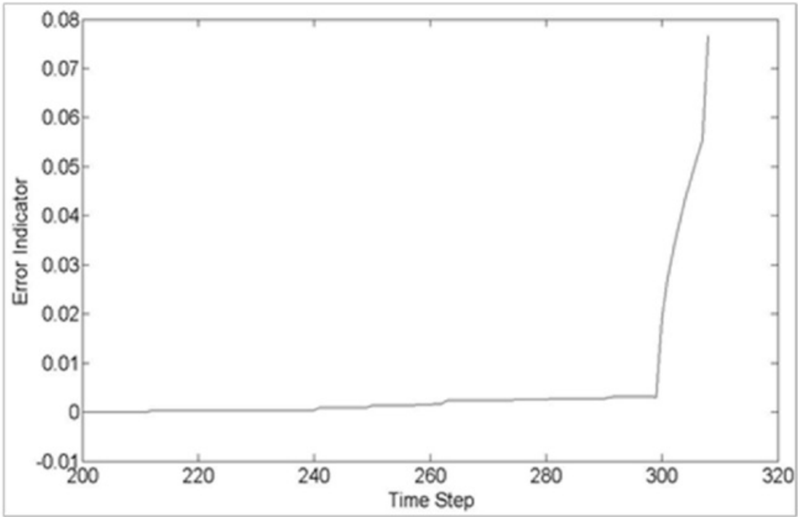

Figure 6. The error indicator (tecnique 1)

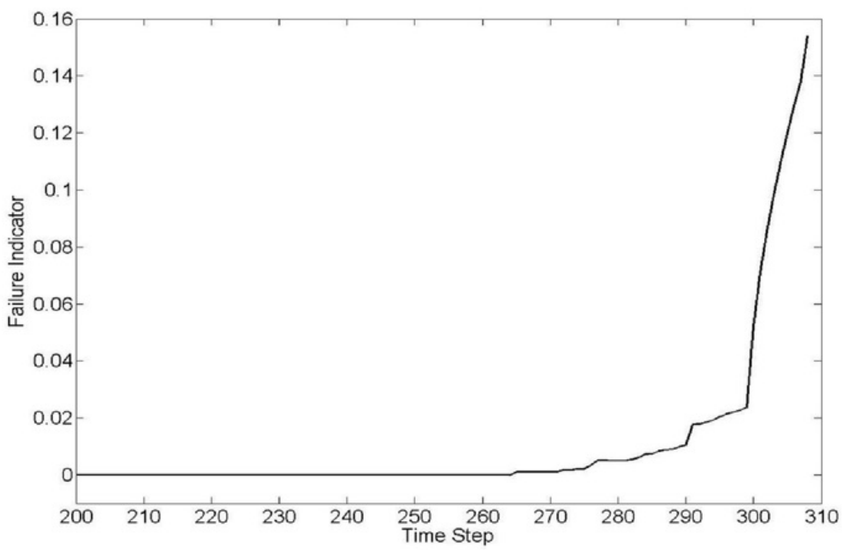

Figure 7. Error indicator (technique 2)

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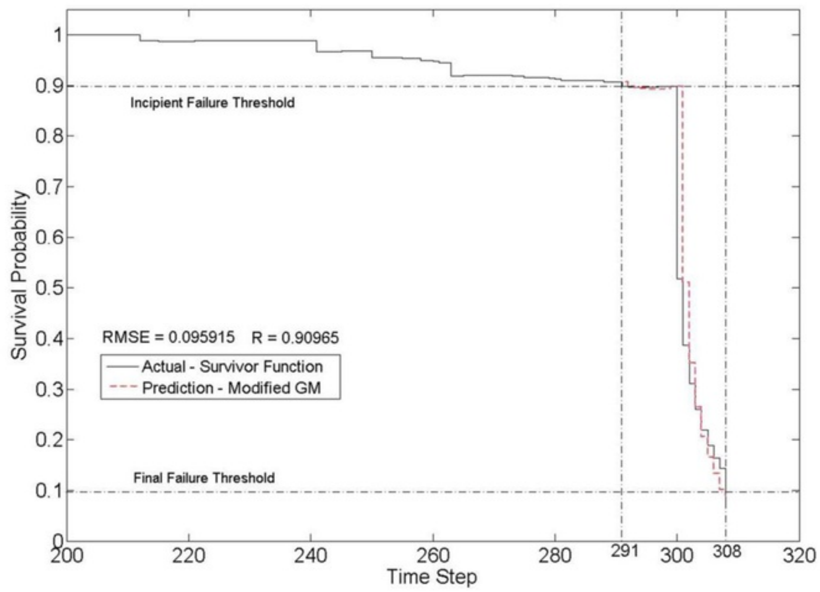

Figure 8. Actual and prediction result (tecnique 1)

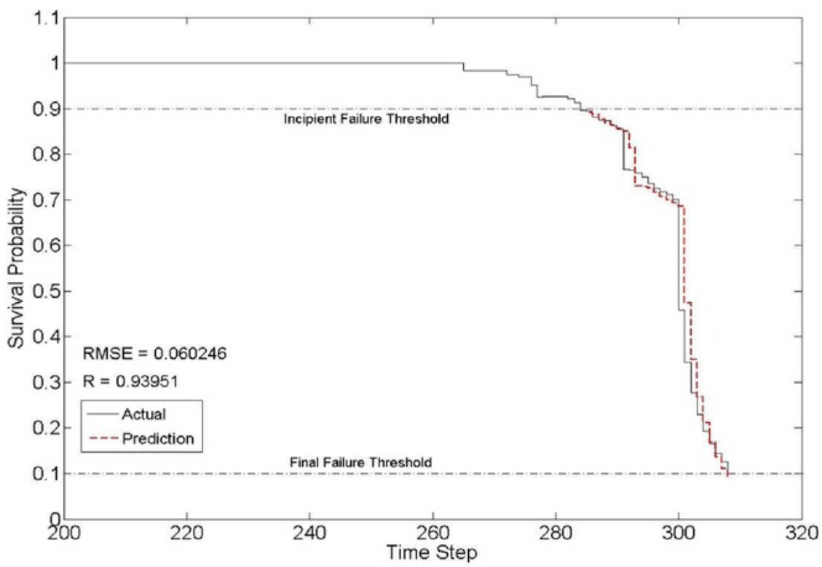

Figure 9. Actual and prediction result (technique 2)

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DISCUSSION

Values of survival probability as the current status of a machine from normal condition to incipient failure threshold were employed to built, trained and validated the model, after that the model was used to predict the future values of survival probability as the future state of a machine from incipient failure threshold to final failure threshold (time of 308).

Predicting performance for technique 1 and technique 2 was presented by root-mean square error and linear correlation as shown in Table 1. According to the result, technique 2 is better than technique 1.

The mechanical prognostics method based on the two techniques is able to predict well the degradation state and remaining useful life of machine as presented in Table 2. Results of experiment and other research are also given in the table. According to the result, technique 1 is better than technique 2.

It is possible to use technique 1 or technique 2 in applications. However, using the both approach in a prognostics application may give the best result.

Table 1. RMSE and R value of prediction

Performance measure	**Technique 1**	**Technique 2**
RMSE	0.095915	0.060246
R	0.90965	0.93951

Table 2. Degradation state and RUL

Condition	**Tech. 1**	**Tech. 2**	**Other Research** (V.T. Tran 2012)	**Experiment**
Incipient Failure	291	284	291	285-290
Final Failure	308	308	306	308
RUL	102	144	84	108-138

CONCLUSIONS

Two techniques according to the approach of normal condition modeling have been proposed in this paper. Normal condition model can be developed using two techniques; namely constant limits (technique 1) and 4th degree polynomial (technique 2). These techniques may support developing of a prognostics method based on grey model.

Actually, two techniques have been discussed according to the approach of normal condition modeling. The prediction performance of both techniques is satisfying by *RMSE* and *R* values. Although there is little different in result among the proposed methods, experiment and other research, the prediction performance is quiet satisfying.

Grey prediction model and one-step-ahead technique was employed as a robust predictor in this research. A modified model of the basic grey model has been made for improving the accuracy of prediction.

ISBN 978-602-17688-9-1

Acknowledgement

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This research was financially supported by the Ministry of Research, Technology and Higher Education through Sam Ratulangi University, Indonesia (SP DIPA - 042.01.2.400959/2016).

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