# A PHM Testbed for Fault Diagnosis of the Machine Tools

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## ABSTRACT

In manufacturing, a machine tool needs to maintain in good condition to prevent degradation in accuracy and disruption in production. All machine tools degrade as it operates, but it is difficult to discern degradation before visual identification, especially detecting degradation in real time. As failure of main elements in the machine result in the significant loss in cost and time, manufacturers need automated and efficient method to diagnose and predict the condition of its elements while in its operation. This paper addresses the Prognostics and Health Management (PHM) architecture for the machine tool, in which the functional model is created from the target system, critical failure modes are identified, sensor units are design to measure failure cause, symptom and the effect on the quality. The proper sensors, features and PHM algorithms are suggested for each of the failure modes as well. To demonstrate and validate this approach, a testbed is designed and operated for machine tools equipment that can implement PHM technique by detecting the faults of critical components, monitoring their degradation and predicting the remaining useful life. After the implementation, cost benefit analysis of the PHM application is conducted. Final goal is to apply and validate the system in the real field.

## 1. INTRODUCTION

In the recent manufacturing process, as the use of automation machine tools increases, productivity improvement, production cost reduction, product diversification and high performance are achieved. In this automatic manufacturing system, the failure of one machine tool has a significant effect on the entire system. However, maintenance systems in industrial field lack the diagnostics capability, which is repaired only after quality degradation or component failure. Therefore, it is necessary to construct more smart maintenance system that can carry out diagnosis and prognosis in real time to minimize downtime of the equipment. In this sense, this paper aims to develop PHM architecture that can help the non-specialist to apply the technology in proper manner and implement the PHM successfully in their field. A testbed is designed to simulate the operation of the machine tools and perform the PHM function according to a set of PHM standards.

## 2. TESTBED DESIGN

In order to design the PHM testbed in the machine tools, international standard ISO 17359 is consulted, which provides a step-by-step description of the method for monitoring the status of all machines and provides an overall approach to performing diagnostics and prognostics. Following the standard, the headstock and the carriage system of the machine tool are chosen as the object based on the survey and interview with the shop floor workers. Failure Mode & Effect Analysis (FMEA) is used to identify the fault of the components and their severity within the headstock and the carriage. Types and positions of the sensor to measure and detect the fault are designed based on the FMEA results. 3D model of the final testbed design is shown in Figure 1.

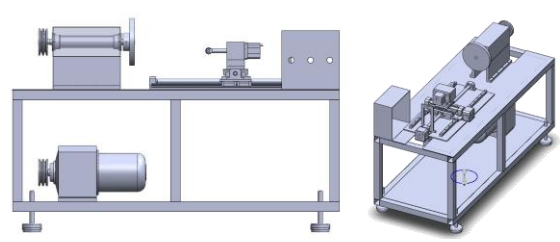


Figure 1. Designed Model of the Testbed

Table 1. PHM Architecture Table for the Machine Tools

| Core units | Major fault components | Fault modes | Common measure (Sensor) | Common feature | Recommended PHM algorithms | |
|---|---|---|---|---|---|---|
| | | | | | Physics based | Data driven |
| Energy/Power | Switch | Circuit open/short | Current | Limit checking | Parameter estimation | Neural networks |
| Hydraulics | Actuator | Seal/Gate abrasion | Pressure | Time-domain characteristic | Particle filter | Neural networks |
| Driving | Motor | Stator winding open/short | Current | Characteristic frequency | Particle filter | Neural networks |
| Power transmission | Bearing | Inner/Outer race spall | Vibration | Characteristic frequency | Particle filter | Hidden Markov Model |
| Control | PLC | H/W & S/W problems | Self-diagnosis program in PLC | | | |
| Machining | Ball-screw | Lead screw spall | Vibration | Characteristic frequency | Kalman filter | Gaussian process |

## 3. PHM ARCHITECTURE DEVELOPMENT

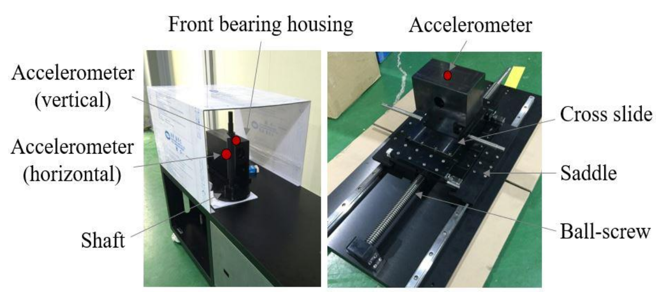
Components of the machine tools are classified into six groups: energy/power, hydraulics, driving, power transmission, control, and the machining unit. PHM architecture is proposed for each of this group to serve as a guideline, in which the major fault components and their failure modes, typical symptoms and measures, and recommended PHM algorithms are provided as illustrated in the Table 1. In the prognostics, two algorithms are suggested for the physics based and data driven approaches respectively, depending on the presence or absence of a physics-model. Authors believe that this guideline may help the non-specialist to have easy access to the PHM technology.

## 4. PHM APPLICATION ON TESTBED

The PHM architecture is applied to the headstock front bearing and the carriage ball-screw, which have been identified as the most important parts via FMEA. The testbed equipment is manufactured as shown in Figure 2. In the testbed, accelerometers are mounted on the bearing and the ball-screw to monitor the vibration, and displacement sensors are installed to check the quality degradation of test equipment, based on the established PHM architecture. In the future, the testbed will be operated to examine the PHM function, in which the failure and quality degradation are applied to each part, faults are diagnosed, the remaining lives are predicted, and the results are validated against the actual fault and end of life.

## 5. CONCLUSION

This paper has developed the PHM architecture of the machine tools and verified its effectiveness by applying it to the testbed simulating the machine tools. If the developed PHM architecture is deployed in the field, non-specialist will gain easily access to the technology, which will result in enormous cost savings.




(a) (b)

Figure 2. Actual Manufactured Testbed
(a) Headstock (b) Carriage

## ACKNOWLEDGEMENT

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## REFERENCES

Saravanan. S., G. S. Yadava, and P. V. Rao. (2003), Machine tool failure data analysis for condition monitoring application. *proceedings of the 11th National Conference on Machines and Mechanism*, pp. 18-20

Dawn An, Nam H. Kim, and Joo-Ho Choi. (2015), Practical options for selecting data-driven or physics-based prognostics algorithms with reviews. *Reliability Engineering & System Safety*, Vol. 133, pp. 223-236

Lee, Jay, et al. (2014), Prognostics and health management design for rotary machinery systems—Reviews, methodology and applications. *Mechanical systems and signal processing*, Vol. 42.1, pp. 314-334.

ISO 17359. (2011), Condition monitoring and diagnostics of machines -- General guidelines

Jardine, A. K. S., Lin, D., & Banjevic, D. (2006). A review on machinery diagnostics and prognostics implementing condition-based maintenance. Mechanical Systems and Signal Processing, 20(7), 1483–1510.

Heng A., S. Zhang, A.C.C. Tan et J. Mathew. (2009). Rotating machinery prognostics: State of the art, challenges and opportunities, Mechanical Systems and Signal Processing, vol. 23 (3), pp. 724-739.

Byington C.S., M.J. Roemer, G.J. Kacprzynski et T. Galie (2002). Prognostic Enhancements to Diagnostic Systems for Improved Condition-Based Maintenance. 2002 IEEE Aerospace Conference, Big Sky, USA.