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Design of Pump Fault Diagnosis System Based on T-FMEA

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Abstract. Water pump is a widely used machine, which is applied to vehicles, vessels, aircraft and other equipment. Once pump develops faults, critical accidents may occur. So the fault diagnosis research and fault diagnosis system design of pump has great realistic significance. Aiming at the centrifugal pump in common use, the study discusses the diagnosis requirement based on testability-orient failure mode and effect analysis (T-FMEA). Then design of the hardware of fault diagnosis system is presented. The software framework is also given in the paper. BP-nerve network is selected to diagnose the failures of pump. The validity and valid of the system is verified through experiment. It reveals that T-FMEA has a certain practical significance for the water pump fault diagnosis research, which can guide the design of fault diagnosis system.

1. Introduction
As the development of science and technology, the military equipment such as vessels and aircraft is becoming more complex, which consists of many mechanical and electronic components. Pump is the typical one with the features and characteristics of mechanical and electronic components. The improvement of fault diagnosis capability would enhance the optional availability and reliability of the whole equipment [1-2].

In the paper, the failure mechanisms and modes of the centrifugal pump are studied based on T-FMECA. Then the failure signals are presented. The fault diagnosis system is built according to centralized framework. Aiming at the signals and modes, the corresponding sensors are selected to monitor the condition of pump. The axis track sensor is newly developed to meet the monitor requirement. The software of the are developed based on labview and BP-nerve network algorithm. The validity and valid of the system is verified through experiment with failures injected. The consequence shows that the system can effectively diagnosis faults of pump and the valid can meet the engineering practical need.

2. Pump failure mechanisms, modes and signals anabasis based on T-FMECA

2.1. failure mechanism, mode and signal

2.1.1. Failure and fault. Failure refers to the event or inoperable state, in which any item or part of an item does not, or would not, perform as previously specified. Fault refers to immediate cause of failure, such as maladjustment, misalignment defect and etc. In this paper, failure equals to fault.
2.1.2. *Failure mechanism*. Failure mechanism refers to the fundamental factors/reasons that lead to the failures. The physical, chemical, electrical, thermal or other process results in failures in other words. The influence on failure mechanism can be heat, chemistry, motion and so on.

2.1.3 *Failure mode*. Failure mode refers to the consequence of the mechanism through which the failure occurs, such as short, open, fracture, excessive. When the pump is the objection for diagnosis, the failure mode should be focus on the next level.

2.1.4 *Failure signal*. Failure signal refers to the signals which caused by failure. They can be optics, heat, vibration or other forms. Not all of the signal can be observed by operator directly. Some would be measure by sensors. It is important for fault diagnosis to get the failure signals.

2.2. *Testability-orient failure mode and effect analysis*

2.2.1. *Failure analysis*. Failure analysis refers to subsequent to a failure, the logical systematic examination of an item, its construction, application, and documentation to identify the failure made and determine the failure mechanism and its basic course.

2.2.2. *Failure mode and effect analysis*. Failure mode and effect analysis refers to a procedure by which each potential failure mode in a system is analyzed, to determine the results or effects thereof on the system and to classify each potential failure mode according to its severity. The formats of FMEA could vary according to the different targets of analysis, such as testability-orient FMEA, maintainability-orient FMEA.

2.2.3 *Testability*. Testability refers to the capability of detecting and locating faults for equipment. It usually used in electronic components. For mechanical and electronic components, testability design is usually equals to the progress of faults diagnosis. Testability is realized by built-in-test (BIT) and other support resources. However, faults diagnosis is realized by a system which consists of hardware and software.

2.2.4. *T-FMEA*. Testability-orient failure mode and effect analysis is used to determine the basic information and incomes for testability design and faults diagnosis. This method consists of six parts. 1) make out the breakdown of the objection, 2) determine the failure mode, mechanism and other basic information of each component, 3) determine the failure evolution feature, 4) determine the failure signal feature, 5) determine the test point or sensors for diagnosis, 6) determine the diagnosis method or technique of each failure mode. When implements T-FMEA, it should be noted that one failure mode may cause one more signals. So the sensors and diagnosis method or technique should be determined for every mode.

2.3. *Pump T-FMECA*

2.3.1. *Pump introduction*. The pump studied in the paper is a centrifugal pump. It consists of electromotor, axis, frame, substrate and pump, as shown in Figure 1.
2.3.2 Pump T-FMECA. According to the steps mentioned in 2.2.4, the analysis of the centrifugal pump T-FMECA is conducted. The four failure modes of four component are studied. The frame and substrate is kinds of structure component, which is not complicated. Their capability can be ensured by lifetime design. The fault diagnosis analysis would be based on the four kinds of failure signals. All of the signals should be monitored by corresponding sensors. Some signal can determine the condition of the pump directly without further analysis. Whereas some other signal, such as vibration, have to be processed by algorithm and software to fault diagnosis [3-4]. Hardware design of pump fault diagnosis system

2.4. Framework of pump fault diagnosis system hardware
The common fault diagnosis system can be dived into three kinds, centralized framework, distributed framework. Centralized framework is simple and of high efficiency. The information flow among the framework is clear. However, it cannot handle a huge number of complex system monitor signals. So it applied to small and simple equipment. Distributed framework is usually used in giant equipment fault diagnosis [5]. The signal mentoring is realised on lower lever in this framework. The framework of pump fault diagnosis system is shown in figure 2.

2.5. Sensors of pump fault diagnosis system
2.5.1. **Electric current sensor.** The electric current sensor in the system is the Hall sensor. The working theory of the sensor is based on Hall effect. It can be fixed in the wires of electromotor, so the electric current can be measured directly.

2.5.2. **Flow rate sensor.** The flow rate sensor in the system is one kind of low rate sensor with type of LWGY, which is a kind of volute flow rate sensors. Volute flow rate sensors are delicacy and easily to maintenance. It would be fixed on the outcome pipe of the pump with the flanges.

2.5.3. **Vibration sensor.** The vibration sensor in the system is electric charge vibration sensor with Type PE. It can prevent the interference of circumstance. The sensor can be fixed on the shell of the pump with nuts. Three vibration sensors are needed to collect the vibration signals from X-Y-Z axises.

2.5.4. **Displacement sensor.** The displacement sensor in the system is permanent magnet perturbation sensor, which is newly developed. The traditional displacement sensor is based on the theory of eddy current, whose size is too big to fix in the pump. Whereas the permanent magnet perturbation sensor is much smaller and the measure accuracy is higher than the latter one.

2.6. **Data gather and primary-processing module of pump fault diagnosis system**

Due to the various failure signals and kinds of sensors in the pump fault diagnosis system, the signal types are not unique. So it is necessary to primary-process and digitalize for the data gather. The primary-processing consists of magnifying and filtering. The data gather and primary-processing module contain the four outcomings and inputs of four kinds of sensors. The inputs are linked by plugs. The signals enter the module and the main system through primary-processing.

2.7. **Main fault diagnosis system**

The failure signal would upload into the main system. They would be shown to the operator after analysed. The display pages contains original data module, time domain and frequency domain analysis module, feature value extract module and fault diagnosis module. All the functions are realised by software.

3. **Software design of pump fault diagnosis system**

The framework of pump fault diagnosis system software is shown in figure 3. The software would firstly recognize and distinguish the pump’s condition based on the failure signals. If the signals are abnormal, the software should confirm and prompt remarks for repairing, maintenance or checking. If they are regular, then continue. The signals are not the original ones but the information after feature value extraction. The software in the study is developed by labview, as shown in figure 4.

![Figure 3. Framework of pump fault diagnosis system software.](image-url)
4. Verify of the pump fault diagnosis system

4.1. Experiment system

The experiment system is established as shown in figure 5. The 380V AC is linked with the electromotor though the wire. Then the electromotor controls the centrifugal pump in the system to realise the function of uptaking and draining away water. The entrance and exit of the pump is linked with water tank by pipes and flanges. The flow rate sensor is fixed on the exit pipe. Other sensors are fixed on the pump. The pump is fixed on the iron frame with bolts.

4.2. Experiment data analysis

Due to the limit of the length of the paper, the vibration data collected in the experiment is analysed as an example. The following six valve after processing is used to train the BP-nerve network to conduct the bearing fault diagnosis, which is maximum(mm, P1), minimum(mm, P2), mean value(mm, P3), center frequency(Hz, P4), number of feature frequency(integer, P5) and various mean value(mm, P6). The modes in bearing fault diagnosis contains inner ring fault, outer ring fault and rolling fault.

Figure 4. Display pages of system.

Figure 5. Experiment system.
The failure data will be processed by the well-trained BP-never network. It shows that the fault detecting rate can reach the goal of 0.95, which reveals that the pump fault diagnosis system can accurately detect and locate the fault of pump.

5. Conclusion
This study presented a method of failure mechanisms, modes and signal analysis based on T-FMEA. The fault diagnosis techniques are also given by T-FMEA aiming at the different modes. The fault diagnosis system is built according to the consequence of T-FMEA. The corresponding sensors are selected to monitor the condition of pump. Then the fault diagnosis system is built. The validity and valid of the system is verified through experiment. It reveals that T-FMEA has a certain practical significance for the water pump fault diagnosis research, which can guide the design of fault diagnosis system.

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