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ScienceDirect
Robotics and Computer-Integrated Manufacturing 24 (2008) 472–487
Robotics and Computer-Integrated Manufacturing
www.elsevier.com/locate/rcim

Improvement of 3P and 6R mechanical robots reliability and quality applying FMEA and QFD approaches

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Received 23 August 2006; received in revised form 31 January 2007; accepted 23 May 2007

Abstract

In the past few years, extending usage of robotic systems has increased the importance of robot reliability and quality. To improve the robot reliability and quality by applying standard approaches such as Failure Mode and Effect Analysis (FMEA) and Quality Function Deployment (QFD) during the design of robot is necessary. FMEA is a qualitative method which determines the critical failure modes in robot design. In this method Risk Priority Number is used to sort failures with respect to critical situation. Two examples of mechanical robots are analyzed by using this method and critical failure modes are determined for each robot. Corrective actions are proposed for critical items to modify robots reliability and reduce their risks. Finally by using QFD, quality of these robots is improved according to the customers' requirements. In this method by making four matrixes, optimum values for all technical parameters are determined and the final product has the desired quality.
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Keywords: Robot; FMEA; QFD; Reliability; Quality; Performance

1. Introduction

In the past few years, extending usage of robotic systems has increased the importance of robot reliability and quality. This problem is more important for robots which are used in hazardous environments. Reliability is also an important factor for industrial and medical robots [1]. Reliability and performance of robotic systems will be improved if failure analysis techniques are used during the design process. Different standard approaches are used during the design. The most important of them are:

- Failure Mode and Effect Analysis (FMEA)
- Fault Tree Analysis (FTA)
- Failure Mode, Effects and Critically Analysis (FMECA)

FMEA and FTA are the most common methods to do this analysis. FMEA is a qualitative method which determines the critical failure modes during the design process. In this method Risk Priority Number (RPN) is used to sort the failure modes with respect to the critical situation. Some corrective actions are proposed for the critical items after sorting the failure modes. Applying this technique during the design improves robot reliability. This technique has been applied for a robot with three degrees of freedom. One of the most interesting results of this research is that under both desired and hard operation conditions, some failure modes have the most risk and failure rate. So the reliability of system would be improved considerably if these failure modes are considered [2]. Korayem has designed a Cartesian robot with three degrees of freedom. Through a FMEA analysis he could figure out that the vibration of end effecter in the bridge model is lesser than in the cantilever model. Also he did some experimental tests to verify this theory [3–5]. Baron and Tondu have presented a deductive method for safety analysis. They have applied this technique for a medical robot. First they analyzed human safety factors, and then by using FMEA and FTA, they obtained different failure modes and their effects on the human. Finally they proposed corrective actions to reduce the hazardous effects [6].

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0736-5845/$ - see front matter © 2007 Elsevier Ltd. All rights reserved.
doi:10.1016/j.rcim.2007.05.003

In the first part of this paper, the FMEA technique is explained briefly. Two examples of industrial robots (3P and 6R) are analyzed by using the FMEA method. All the potential failure modes for these robots are analyzed and their RPN numbers are calculated. Then corrective actions for critical items are proposed. In the next part QFD technique, is used for 3P and 6R robots in order to improve the quality. In this analysis, designers focus on improving quality parameters which are customers' needs. Hence the most important customers' requirements from these robots are gathered. Then different steps of design and producing robot are planned and organized according to these requirements. The final product has the customer's desired quality and in competition with other rivals in the market, this product would succeed.

2. FMEA

The Design Potential FMEA supports the design process in reducing the risk of failures (including unintended outcomes) by:

- Aiding in the objective evaluation of the design, including functional requirements and design alternatives.
- Evaluating the initial design for manufacturing, assembly, service, and recycling requirements.
- Increasing the probability that potential failure modes and their effects on system and system operation have been considered in the design/development process.
- Providing additional information to aid in the planning, thorough and efficient design, development, and validation program.
- Developing a ranked list of potential failure modes according to their effect on the "customer," thus establishing a priority system for design improvements, development, and validation testing/analysis.
- Providing an open issue format for recommending and tracking risk-reducing actions, and
- Providing future reference, (e.g. lessons learned), to aid in analyzing field concerns, evaluating design changes, and developing advanced designs.

In each FMEA analysis, some suggested evaluation criteria are used to evaluate three factors for each failure mode. These factors are:

- Severity
- Occurrence
- Detection

The RPN is calculated as follows:

$$\mathrm{RPN} = S \times O \times D, \tag{1}$$

where S is the severity, O the occurrence, and D the detection ranking. Within the scope of the individual FMEA, this value (between 1 and 1000) can be used to rank order the concerns in the design [7]. Different steps of this analysis are illustrated in Fig. 1.

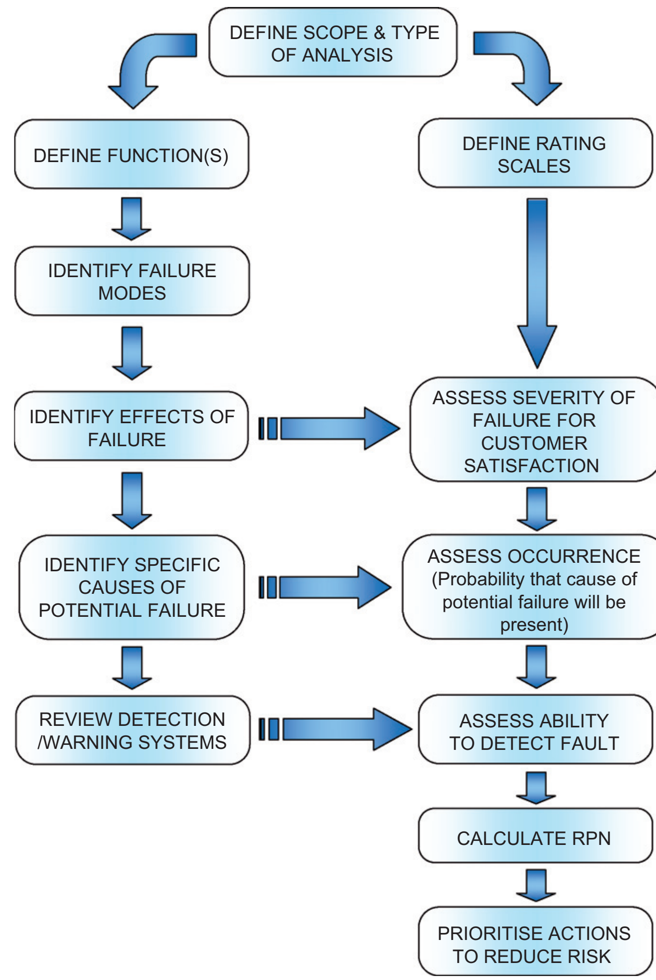

Fig. 1. FMEA process flow chart [8].

3. Applying FMEA to improve reliability of two industrial robots

3.1. Case study I: 3P robot

The first case study is a Cartesian robot which has three degrees of freedom. Bridge model has been used to provide linear movement in each direction. Experiments and some analysis have shown that the bridge model provides more stable and suitable movement than the cantilever model, as shown in Fig. 2. To achieve high precision in Y and Z directions, two ball screws have been used for power transmission from gearbox to the axis in each direction. Desired precision in X movement is lesser than in other directions, so a gear and pinion system has been used for power transmission in the X direction.

Linear movements in three directions are provided by using five linear bearings. For X- and Y-axis two linear bearings have been used. In Z direction one linear bearing

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