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MAINTAINABILITY ASSURANCE OF THE INDUSTRIAL ROBOTS

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Abstract: In this paper, the maintainability assurance of industrial robots was achived by renewal policies. For this purpose, the reliability modelling of industrial robots was performed by a goodness-of-fit test. A case study was conducted to demonstrate the application of the approach.

1. INTRODUCTION

The structure of the industrial robots is composed by various components (electronics, optics, mechanics, software), with a higher and higher degree of intelligence, so that the reliability estimation of these systems becomes a more complex problem. The continuous developments of industrial led to the construction sytems that are susceptible to frequent failures.

Taking into account this aspect, the paper is focused on the maintainability assurance of this equipments. For this purpose, the reliability modelling of industrial robots must be performed. The reliability modelling of industrial robots can be done by using the failure notion, in which case at least one of industrial robots characteristics transgresses its prescribed limits.

The main problems regarding the knowledges about the relationships, influences and causal determination between failure phenomena of the industrial robots is the few quantitative information existed [2]. This situation is due to the new technical areas integrated in the structure of these systems, which lead to a relatively high degree of uncertainty in prediction the behavior of the industrial robots.

2. RELIABILITY MODELLING OF THE INDUSTRIAL ROBOTS

The reliability modelling of industrial robots requires the estimation of reliability componets. Industrial robots are using using one a mechanical structure, microprocessors, sensors and systems for action and control.

Reliability measures of industrial robots are defined using the statistical model for the time to failure. The statistical model for reability is the cumulative distribution function(cdf). Denoted by F(t), the cdf represents the probablity that industrial robot fails after a specified cycles of functions.

The association between a distribution law and the failure mechanism must be realised by the psyhical interpretation and experimental data. The essential step in adopting the distribution law is based on the theory of hypothesis testing . According to this theory, the null hypothesis H_0 regarding the distribution law and the alternate hypothesis H_1 which excluded the distribution law selected by the H_0 hypothesis are formulated. A decision between the two hypothesis is taking according to a goodness-of-fit test and is affected by the first(α) and second (β) risks. One of the most used a goodness-of-fit test is the

Kolmogorov-Smirnov test, which use the time to failure of the component under the observation. For this test, the distribution law is accepted if and only if [1]:

$$\sup_{1\le i\le n}\left|F(t)-\hat{F}(t)\right| < e_{1-\alpha}(n) \tag{1}$$

where F(t) and $\hat{F}(t)$ are the true and estimated cdf and $e_{1-\alpha}(n)$ is the 1-α percentile of the Kolmogorov-Smirnov distribution.

The structural reliability modelling impose the knowledge of the components reliability, taking into account the failure criteria of the industrial robot's components. Generally, the industrial robot structure is very complex and the analytical reliability modelling becomes difficult. In such cases, a numerical evaluation of the reliability may be performed by Monte-Carlo simulation.The method consists of generating possible states of components according to their reliability functions and evaluating the relaibility of each combination of individual states [1]:

$$\hat{R}_s = \frac{\sum_{i=1}^{n} S_i}{n} \tag{2}$$

where S_i is the value of the structural function for simulation i and n is the number of simulations.

3. MAINTAINABILITY ASSURANCE OF INDUSTRIAL ROBOTS BY RENEWAL POLICY

A renewal policy is specified by the scheduled times of preventive renewals. In the event of systems failure, renewals are carried out at random times, whereas preventive renewals may be deterministic or random events, according to the type of renewal policy. Several criteria may be used in formulating renewal policies [3,4]. A renewal policy may be designed so that operational reliability exceeds a specified value. Another criteria are that the renewal policy should maximize the system availability or minimize the average maintenance cost rate. In any of these criterions, it is important to evaluate the maintenance cost. To this end, the cost of a renewal upon failure is taken as c_f and the costs of preventive renewals are c_p ($c_p<c_f$).

One of the most used deterministic renewal policy is the block replacement policy (BRP). According to this , the system is restored to its initial state either upon failure or at equally time intervals kT (k=1,2,...). The time interval between to successive preventive renewals, which starts at kT and lasts until (k+1)T, may be determined so that the reliability function should not be lower than a specified level R_0:

$$R(T) \ge R_0 \tag{3}$$

The total cost maintenance cost per unit time is [3]:

$$c_{BRP} = \frac{c_p + c_f \cdot H(T)}{T} \tag{4}$$

where H(T) is the mean number of failures in [kT,(k+1)T] interval. The difficulty in design of the BRP policy appears in the impossibility of computing the H(t) function, for several life distribution. In such cases, for the stationary stage, an approximate formula can be used [3]:

$$H(t) \cong \frac{t}{m} + \frac{D^2(t) - m^2}{m^2} \tag{5}$$

where m is the mean and $D^2(t)$ is the dispersion of the time to failure. This cost must be compared to the average maintenance cost when no preventive renewals are carried out. We describe this situation as the failure replacement policy (FRP). The average maintenance cost in the stationary state of the renewal process in this case is :

$$c_{FRP} = \frac{c_f}{m} \tag{6}$$

Between the random renewal policy, one of the most used is the age replacement policy (ARP). In this random renewal policy, preventive renewals is performed if and only if the system has reached a specific age x. If the criterion of a specified reliability level is employed, the replacement age x results equal to the period T given by equation (3) for BRP case. The maintenance cost of the system is considered equal to c_f if the system fails before it reaches age T and equal to c_p in the opposite case. Dividing the average maintenance cost by the mean lifetime, we get:

$$c_{ARP} = \frac{c_f \cdot F(T) + c_p R(T)}{\int_0^T R(t)dt} \tag{7}$$

where F(t) is the cumulative distribution function of the industrial robot and R(t) the reliability function.

4. CASE STUDY

The theoretical considerations presented were applied for an industrial robots. Three laws were proposed to describe the time to failure of the equipment: Weibull, alpha, power [5]. A Kolmogorov-Smirnov goodness-of-fit test was performed to adopt the distribution law. The risk of the first order was adopted at $\alpha_1 = 0.10$. and finally power law was adopted. the parameters of the law were computed: $\hat{\delta} = 2.319, \hat{b} = 9480.23$.

In order to estimate the structural reliability of the manipulator, the following structure function was adopted:

$$S = \prod_{i=1}^{n} x_i \tag{10}$$

The possible values of the state vector $X=(x_1,x_2,\ldots x_n)$ were obtained by simulation, using the Monte Carlo method. The simulation of state vector and the estimation of the reliability function were computed by the C++ program, too. Taking into account the reliability function of each components, the structural reliability resulted as R_{min}=0.79.

The criteria used in design the renewal policy was the minimum reliability level R_{min}=0.79. We have supposed that for the BRP policy the cost of preventive renewal is $(c_p / c_f)_{BRP} = 0.25$ and for the ARP policy is $(c_p / c_f)_{ARP} = 0.3$. Taking into account the relation (6), the preventive renewal must be done after T=4837 cycles of function. The costs c_{BRP}, c_{ARP} and c_{BRP} were also computed: $c_{BRP} = 0.92 \cdot 10^{-4} \cdot c_f$, $c_{ARP} = 0,89 \cdot 10^{-4} \cdot c_f$, $c_{FRP} = 1,51 \cdot 10^{-4} \cdot c_f$. Because the average maintenance cost rate in the ARP renewal policy is less than in the BRP renewal policy ($c_{ARP} < c_{BRP} < c_{FRP}$), the ARP renewal policy was adopted. The replacement age was resulted equal to 4837 cycles of function and the reliability function does not fall below the minimum 0.79 level.

5. CONCLUSIONS

The adoption of the reliability model of the time to failure of the industrial robots allows the estimation of the reliability measures of these equipments. The renewal policy may be designed and the maintainability assurance can be achieved

6. REFERENCES

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