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Development of an optimal preventive maintenance model based on the reliability assessment for air-conditioning facilities in office buildings

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Abstract

The purpose of this study is to examine the failure trend of HVAC systems in high-rise office buildings using the reliability assessment, and propose a method of predicting an optimal inspection period for condition-based preventive maintenance (CBM) using the Monte Carlo method, in point of view of randomness and independency between failure and inspection. This study describes the probability process method of measuring the effect of condition-based preventive maintenance on HVAC system's reliability and optimization of condition-based preventive maintenance. A simulation model is presented to analyze condition-based preventive maintenance through a fixed period maintenance inspection by maintenance personnel conducted to detect failure occurring. Based on this simulation model, the effects of condition-based preventive maintenance on units of HVAC system's reliability are quantitatively obtained, and the mean time between failures of units under CBM action is suggested. In addition, the basic characteristics of the condition-based preventive maintenance are analyzed by sensitivity analysis. As a result of this study, the method to predict an optimal inspection period is also suggested in order to increase the reliability of units, and effect on expected profit of optimal preventive maintenance inspection period is computed.

Keywords: Heating, ventilating & air-conditioning system (HVAC); Reliability-centered maintenance; Mean time between failures; Condition-based preventive maintenance; Monte Carlo simulation; Optimal inspection period

1. Introduction

1.1. Backgrounds and aim

As office buildings are getting bigger, the information technology (IT) and office automation (OA) equipment are developing and the facility systems are complex, the demand for building facilities' reliability is rising. Especially, the reliability of HVAC systems is seriously considered as an important aspect of occupants' productivity and comfort. To improve the reliability of building facilities, the most important issues requiring immediate attention are to grasp and remove the factors causing problems in all steps of the life cycle such as building planning, design, construction, maintenance and to evaluate quantitatively the reliability model of failure history data [1].

There are two ways to improve the reliability of an air-conditioning facility. One way is to design HVAC systems with special consideration for redundancy and the other way is to implement preventive maintenance. The former is the design mode which is necessary in the case where air-conditioning function requires a high-degree of reliability such as telecommunication rooms and computer rooms [2] and the latter is the maintenance mode which should be applied to most HVAC systems in general buildings. The preventive maintenance can be divided into time-based preventive maintenance and condition-based maintenance. The time-based preventive maintenance is mainly applied to the non-repairable items which have a life distribution and its research and theory are established as a maintenance policy by Barrow [3]. The condition-based preventive maintenance, also called prediction maintenance, is applied to the items where failure happens accidentally [4]. Because the HVAC system's reliability sometimes breaks down within a life period of durability through Weibull

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Nomenclature

A	expected profit by CBM per unit time
A_1	expected profit that is obtained by reducing the emergency maintenance by CBM
A_2	expected profit of preventive maintenance by CBM
A_3	expected profit by inspection
C	constant
C_1	loss cost of emergency maintenance
C_2	emergency maintenance unit cost
C_3	preventive maintenance unit cost
C_4	inspection unit cost
D	number of reduction by CBM
$F_{E(t)}$	life distribution function of average fault occurrence period
$F_{M(t)}$	life distribution function of MTBF
g	instant detecting probability just before failure stop
g_I	probability of fault instant detection of simplified inspection
g_{II}	probability of fault instant detection of detailed inspection
g_a	probability of succeeding in fault instant detection
g_{ai}	probability of succeeding in fault instant detection at ith inspection
g_b	probability of failing of the fault instant detection
$g_1, g_2, \ldots, g_k$	probability of fault instant detection of inspection
N	number
N_a	success number of detecting fault
Q	inspection frequency, or number of inspection, 1/h
t	time
t_D	$t_D = t_M - t_E$, h
t_E	fault occurrence period, or the time taken to the failure from occurrence, h
T_E	average fault occurrence period, h
T_K	CBM's average preventive maintenance period, h
t_L	lead time, the time taken to the failure from fault detection, h
t_M	MTBF, failure occurrence period, h
T_M	original MTBF, MTBF without preventive maintenance, h
T_{M2}	CBM's MTBF, h
t_P	diagnosis time, h
T_P	average diagnosis time, h
T_S	average inspection period, h
t_S	inspection period, h
t_{S1}	simplified inspection period, h
t_{S2}	detailed inspection period, h
X_1	average number of emergency maintenance occurrence per unit time, h
X_2	average number of preventive maintenance occurrence per unit time, h

Greek symbols

α	preventive maintenance success probability
β	shape parameter
η	scale parameter
ξ	random digits

analysis,[1] most of the main air-conditioning equipment is compatible for condition-based preventive maintenance. Condition-based prevention maintenance with the object of detecting symptoms of a failure is the mode to decrease an emergency stop and maintenance through the execution of preventive measures that is on the basis of consecutive operating condition's supervision by the real time-observation system and regular inspection by maintenance personnel. Such a mode makes an equipment's MTBF augment [5]. Therefore, it is necessary to present the optimal inspection period as a preventive maintenance policy to improve the reliability of facilities utilizing mean time between failures (MTBF) based on reliability statistical information.

In this research, failure trend is analyzed through investigation of the failure history data for the units and parts of the main HVAC systems in high-rise office buildings located in Seoul, Korea. Furthermore, the models of detailed inspections and simplified inspections applied in practical maintenance are established and grasp the independence between failure occurrence's randomness and inspection. Then the method to seek the optimal inspection period is shown by the Monte Carlo simulation, where the probability process containing the probability distribution of the condition-based preventive maintenance models in the HVAC system.

[1] The Weibull distribution was originally derived by Swedish engineer and statistician Waloddi Weibull, who used it to describe the breaking strength of materials and life properties of ball-bearings. In essence, the distribution was already known under the guise of the extreme value distribution of smallest value and has become the leading method for fitting life data. Although primarily a tool for solving reliability problem, Weibull analysis has wider application, including maintainability. The Weibull Probability Law was designed to accommodate increasing, decreasing, and constant failure rate. The Weibull probability law may be characterized by three parameters
β = the shape parameter,
η = the characteristic lifetime,
γ = the location parameter.
The shape parameter indicates whether the failure rate is increasing, decreasing, or constant. When shape parameter $\beta < 1$, we are dealing with a failure rate that decreases with time; if $\beta > 1$, we are dealing with an increasing failure rate; and if $\beta = 1$, the failure rate is constant.