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ITJ

ISSN 1812-5638

INFORMATION TECHNOLOGY JOURNAL

ANSInet
Asian Network for Scientific Information
308 Lasani Town, Sargodha Road, Faisalabad - Pakistan

Information Technology Journal 12 (21): 6107-6110, 2013
ISSN 1812-5638 / DOI: 10.3923/itj.2013.6107.6110

Reliability Analysis of Air-conditioning Refrigeration System for Chery A3 Automobile

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Abstract: The study analyzes the factors that cause failure of air-conditioning system and builds the corresponding fault tree. The failure spectrum of air-conditioning system is constructed through qualitative analysis of the fault tree. And theoretical researches of the quantitative analysis results are also carried out. The study provides the theoretical foundation of automobile air-conditioning system's design and maintenance.

Key words: Air-conditioning, refrigeration, reliability, fault tree analysis

INTRODUCTION

The principle of automotive air-conditioning refrigerating is that air's volume increase sharply and huge heat is absorbed when the high pressure refrigerant is released which as same as the ordinary household air-conditioning. The compressor is installed beside the engine, condenser is in the front of the car radiator and the evaporator is in the car. While working, low pressure gaseous refrigerant from the evaporator turn into the high temperature and pressure gas which cold down and turn into the low temperature and high pressure liquid when flowing through condenser cooling pipe. After being dehumidificated and buffered by drier receiver, the liquid flow into expansion valve at a rather stable pressure and finally return to the evaporator after being throttled and depressurized. The refrigerant absorbs a lot of heat on meet a low temperature environment. Temperature in car decrease since the air flow through evaporator constantly. Liquid refrigerant flowing through the evaporator turn into a low-pressur gas again which would be inhaled into compressor for the next cycle.

Obviously, fault analysis for air-conditioning refrigerating is essential and the Fault Tree Analysis (FTA) is one of the main methods of fault analysis (Xu, 2003). With the analysis of various factors which may cause the failure of the refrigeration system, the study plotted the diagram of FTA, determined all kinds of failure mode and probability of refrigeration system and lastly obtained failure spectrum which provide the reference for enhancing the reliability of air-conditioning refrigerating system.

FAULT TREE ANALYSIS (FTA)

Fault tree is a special kind of inverted logical tree using symbols of events and logical gates to describe causality between events (Sun, 2007). The top event, an undesirable event and the priority of the fault tree's construction, should be considered in the first place. Then the direct cause to the top event, such as faults caused by hardware, software as well as environmental factors, should be detected as the second event in further. Finally, all events cause to the second events should be find out to serve as the third events and the analysis progress run in this way until the ultimate events were found which is the whole progress of the fault tree's construction (Beyea, 2005).

CONSTRUCTING THE FAULT TREE OF AIR-CONDITIONING REFRIGERATING SYSTEM

The fault tree was extended from the failure of the refrigerating system (Fig. 1) which served as the top event. Refrigeration system is the core of air-conditioning,

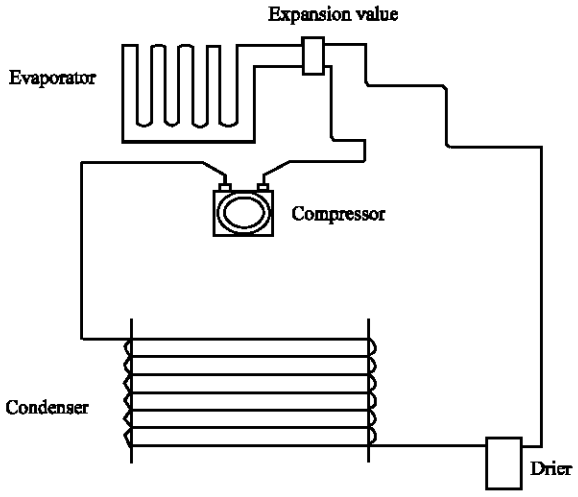

Fig. 1: Cycle diagram of refrigerating system

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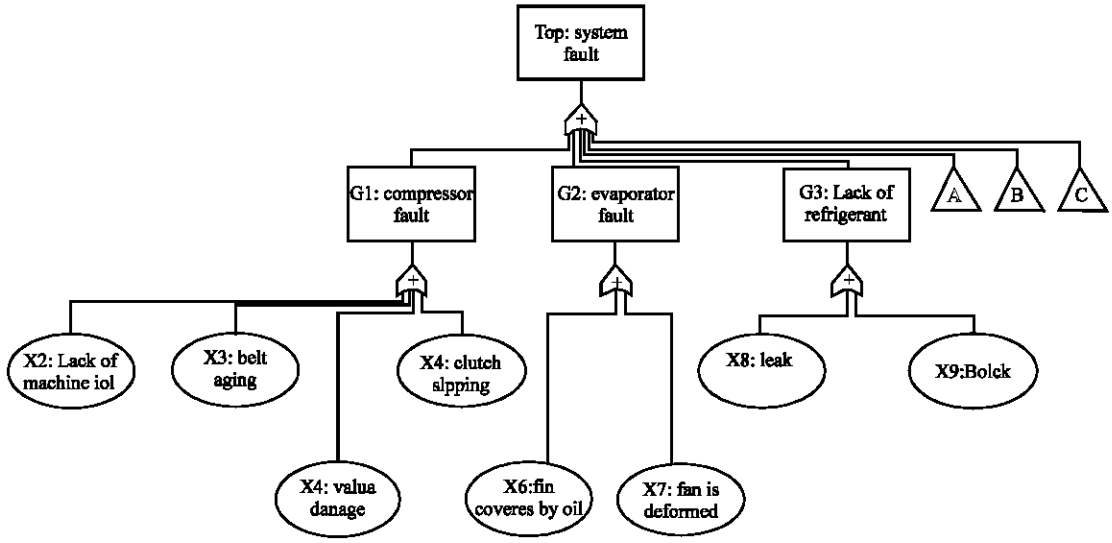

Fig. 2: Part 1 of the fault tree

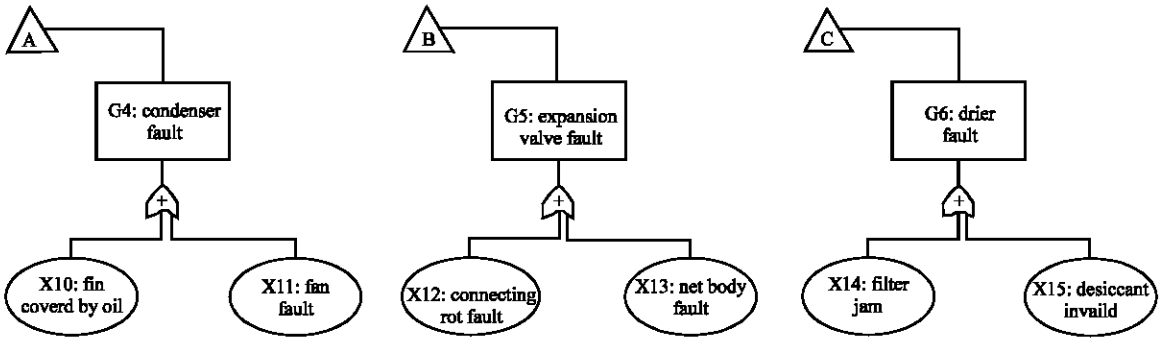

Fig. 3: Part 2 of the fault tree

in which bearing the effects of temperature, environment, vibration and other factors involved links such as the design, manufacturing, installation, service and so on and the bottom events can be traced through those links. The fault tree was generated by using appropriate symbols as events and others as logical gates for connecting the events into a tree (Fig. 2 and 3).

QUALITATIVE ANALYSIS OF FAULT TREE OF REFRIGERATING SYSTEM

Qualitative analysis is to find all the Minimum Cut Sets (MCS) of fault tree (Fu, 2001). Cut set is a collection of the several bottom events of the fault tree which may lead to occurring of the top event (Geyan, 2007). And the top event does not happen when any bottom event of the cut set was removed. According to the obtained minimum cut sets, the weakest link in the system can be determined (Huang, 1990).

There are plenty of methods to find the cut set such as downward method as well as upward method which was adopted here. The upward method is to write the logical expression between the rectangular event and its superior neighboring event and to put the lower expression into the upper expression from the bottom up (Huang, 2005). Every time the obtained logical expression should be simplified until the top event was gained (Jiang, 2005). In the fault tree the study constructed, TOP represent the top event, G middle event and X the bottom event which were numbered as following table (Table 1)

Each logical expression of event was written from the bottom up as follows:

G6 = X14+X15
G5 = X12+X13
G4 = X10+X11
G3 = X8+X9
G2 = X6+X7
G1 = X2+X3+X4+X5

Table 1: Codes of the events

G1:compressor fault	G2:evaporator fault	G3:lack of refrigerant
G4:condenser fault	G5:expansion valve fault	G6:liquid drier fault
X1:blower fault	X2:lack of machine oil	X3:belt aging
X4:exhaust and intake valve damaging	X5:clutch slipping	X6:fin is covered by oil
X7:fin is deformed	X8:refrigerator leak	X9:refrigerator jam
X10:fin is covered by oil	X11:fan fault	X12:connecting rot fault
X13:net body block	X14:filter jam	X15:desiccant invalid

TOP = G1+G2+G3+G4+G5+X1=X15+X14+X13+X12+X11 +X10+X9+X8+X7+X6+X5+X4+X3+X2+X1

After all middle events was replaced by the bottom events, the expression was simplified by absorbing process and all the minimum cut set was obtained (Ge, 2008): [X1], [X2], [X3], [X4], [X5], [X6], [X7], [X8], [X9], [X10], [X11], [X12], [X13], [X14], [X15]. The fault spectrum is the assemble which consist of all minimum cut sets : { [X1], [X2], [X3], [X4], [X5], [X6], [X7], [X8], [X9], [X10], [X11], [X12], [X13], [X14], [X15]}.

Fault spectrum reflects the entire system failure mode. In order to enhance the reliability of air-conditioning refrigerating system, the probability of bottom event in the fault spectrum must be reduced firstly (Wang, 2008).

QUANTITATIVE ANALYSIS OF FAULT TREE

The task of quantitative analysis of fault tree is to determine the probability of the top event in term of bottom event (Wang, 2011). There are two major methods in quantitative analysis (Zhu, 1997): One is calculating probability according the admissible and repelling law while the other is the structure function. The study which takes advantage of the former calculates the probability of the top event as follows:

The minimum cut sets of fault tree is known:

$$C_1 = \{c_{1,1}, c_{1,2}, \ldots, c_{1,n_1}\} = \left\{\bigcap_{j=1}^{n_1} c_{1,j}\right\}$$

$$C_2 = \{c_{2,1}, c_{2,2}, \ldots, c_{2,n_1}\} = \left\{\bigcap_{j=1}^{n_1} c_{2,j}\right\}$$

$$C_m = \{c_{m,1}, c_{m,2}, \ldots, c_{m,n_1}\} = \left\{\bigcap_{j=1}^{n_1} c_{m,j}\right\}$$

Obviously, the top event would happen only if all the bottom events of one minimum cut sets occurred:

$$\{TOP\} = \left\{\bigcup_{i=1}^{m} C_i\right\}$$

Hence, the probability of the top event is:

$$P\{TOP\} = P\left\{\bigcup_{i=1}^{m} C_i\right\}$$

According to the admissible and repelling law, the formula can be extended as below (Yan, 2011):

$$P\{TOP\} = \sum_{i=1}^{m} P\{C_i\} - \sum_{i=1}^{m-1}\sum_{j=i+1}^{m} P\{C_i \cap C_j\} + \sum_{i=1}^{m-2}\sum_{j=i+1}^{m-1}\sum_{k=j+1}^{m} P\{C_i \cap C_j \cap C_k\} - \ldots + (-1)^{m-1} P\{C_1 \cap C_2 \cap \ldots \cap C_m\}$$

For the intricate fault tree which the calculation process is very complicated, some outstanding computer aided analysis software, such as CAFTA, can be taken advantage to solve the problem (Chen, 2001). The CAFTA consist of three modules: CAFTA, FDA and Safety which realizing the function of data management, calculation and analysis of the outcome. CAFTA can obtain output results qualitatively and quantitatively only with the input of the failure distribution of each bottom events which greatly facilitate the process of failure analysis.

CONCLUSION

The study constructs the fault tree with using the refrigerating fault as the top event which can directly reflect the various mode of failure. Then the fault spectrum is obtained by using the upward method and the reliability of the system can be improved by enhancing every basic failure elements. The cause of refrigeration system failure relates to raw material, processing method and technology, structure design and so on. Therefore it's certain difficult on failure analysis of the bottom events which need investigating and collecting of air-conditioning system for a long time.

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