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Design of a hinge kit system in a Kimchi refrigerator receiving repetitive stresses

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ABSTRACT

Based on field data and a tailored set of accelerated life tests, the hinge kit system of a closing door in a Kimchi refrigerator was redesigned. Using a force and moment balance analysis, the simple mechanical loads from the closing of the door were evaluated. The failure modes and mechanisms found experimentally were similar to those of the failed sample in the field. Failure analysis, accelerated life tests and corrective action plans were used to identify the key control parameters and level for the mechanical hinge kit system. The missing controllable design parameters of the hinge kit system in the design phase included the corner rounding and rib of the housing hinge kit, the oil sealing method of the oil damper, and the material of the cover housing. After a tailored series of accelerated life tests with corrective action plans, the B_1 life of the new hinge kit design is now guaranteed to be over 10 years with a yearly failure rate of 0.1%.

1. Introduction

Fig. 1 shows the Kimchi refrigerator with the newly designed hinge kit system. When a consumer closes the door, they want to close it conveniently and comfortable. For this function, the hinge kit system needs to be designed to handle the operating conditions subjected to it by the consumers who purchase and use the Kimchi refrigerator. The hinge kit assembly consists of the kit cover, shaft, spring, oil damper, and kit housing, as shown in Fig. 1B.

In the field, the hinge kit assembly in the refrigerators had been fracturing, causing the door not to close easily. Thus, the data on the failed products in the field were important for understanding the usage environment of consumers and helping to pinpoint design changes that needed to be made in the product.

Robust design techniques, including statistical design experiment (SDE) and Taguchi methods [1], were developed by statisticians many years ago. In particular, the Taguchi methods describe the robustness of the system for evaluation and design improvement – called quality engineering [2,3] or robust engineering [4]. Robust design processes include concept design, parameter design, and tolerance design [5].

Taguchi's robust design method uses parameter design to place the design in a position where random "noise" does not cause failure and to determine the proper design parameters and their levels [6]. The basic idea of parameter design is to identify, through exploiting interactions between control factors and noise factors, appropriate settings for the control factors that make the system's performance robust in relation to changes in the noise factors. Thus, the control factors are assigned to an inner array in an orthogonal array, and the noise factors are assigned to an outer array.

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Nomenclature

AF	acceleration factor
B_X	durability index
$C1$	housing design of hinge kit
$C2$	oil damper sealing structure
$C3$	cover housing material
$F(t)$	unreliability
F	force, N
F_1	impact force under accelerated stress conditions
F_0	impact force under normal conditions
h	testing cycles (or cycles)
h^*	non-dimensional testing cycles, $h^* = h/L_B \geq 1$
KCP	key control parameter
KNP	key noise parameter
L_B	target B_X life and $x = 0.01X$, on the condition that $x \leqslant 0.2$
M	moment around the hinge kit system, kN m
M_1	impact force under accelerated stress conditions
M_0	impact force under normal conditions
M_A	moment due to the accelerated weight, kN m
M_{door}	moment due to the door weight, kN m
n	the number of test samples
$N1$	consumer door open/close force, kN
R	radius of the hinge kit system, m
r	failed numbers
S	stress
S_1	mechanical stress under accelerated stress conditions
S_0	mechanical stress under normal conditions
t_i	test time for each sample, h
T_f	time to failure, h
x	the required target, $x = 0.01X$, on condition that $x \leqslant 0.2$
W_A	accelerator weight, kg
W_{door}	door weight, kg

Greek symbols

η	characteristic life

Superscripts

β	shape parameter in a Weibull distribution
n	the stress dependence, $n = -\left[\frac{\partial \ln(T_f)}{\partial \ln(S)}\right]_T$

Subscripts

0	normal stress conditions
1	accelerated stress conditions

However, a large number of experimental trials in the Taguchi product array may be required because the noise array is repeated for every row in the control array. Alternative methods, such as the combined array approach, were proposed [7,8]. However, for a simple mechanical structure, a lot of design parameters should be considered in the Taguchi method's robust design process. Those products with the missing or improper minor design parameters may result in recalls and loss of brand name value.

Based on the analysis of failed products in the field, accelerated life testing (ALT) with the new concept B_X and sample size, can be considered as an alternative parameter study [9,10]. Failure analysis of the field data pinpoints the missing key control parameters in the design process. ALT can identify the key control parameter of the newly designed mechanical system and the proper choices of its levels.

The key control parameters precipitated by ALT may not represent those occurring in the field because of inconsistencies in the types and magnitudes of the loads applied during testing. Moreover, the number of test samples and the test durations are usually insufficient to uncover some occasional failure modes. ALT should be performed with sufficient samples and testing time, and with equipment designed to match expected product loads.