Mini Review
Open Access
CrossMark

Reliability design of mechanical systems such as compressor subject to repetitive stresses

Abstract

Parametric accelerated life testing (ALT) is developed as a reliability methodology to correct the designs of a mechanical system subjected to repetitive pressure loading. An accelerated load was applied to selected samples to uncover the design parameters affecting reliability during the design process of a compressor. The developed method consisted of a parametric ALT plan, load analysis, a tailored series of parametric ALTs with action plans, and evaluation of the final compressor design to ensure the reliability criteria were satisfied. As a test case, reciprocating compressors from French-door refrigerators returned from the field were studied. Disassembling the failed compressors revealed that the suction reed valve had fractured. In the first ALT, the failed samples from the field were reproduced. The root cause of the failure came from the sharp edges of the valve plate and an overlap between the suction reed valve and the valve plate. As corrective actions, the valve plate in the compressor system was modified to increase the trepan size and a ball pinning process was added. There were no problems during the second ALT. After these parametric ALTs with corrective action plans were conducted, the modified compressor was expected to achieve the reliability of a 10years life with an accumulated failure rate of 1%.

Keywords: reliability design, suction reed valve, fracture, parametric accelerated life testing, faulty designs

Volume 6 Issue 1 - 2020

Seongwoo Woo,[1] Wassie Molla Salilew,[2] Y Teklay,[2] M Seged[2]

[1]Faculty of Mechanical Engineering, Addis Ababa Science and Technology University, Ethiopia

[2]Lecturer of Mechanical Engineering, Addis Ababa Science and Technology University, Ethiopia

Correspondence: Seongwoo Woo, Faculty of mechanical engineering, Addis Ababa science and technology university, Ethiopia, Tel +251900476711, Email twinwo@yahoo.com

Received: February 19, 2020 | **Published:** March 09, 2020

Introduction

A refrigerator provides cold air from the evaporator to the freezer and refrigerator.[1] Typically, refrigerator uses the vapor-compression refrigeration system that undergoes the phase changes of the refrigerant. Total components in a domestic refrigerator might be 3,000 pieces and expected to have at least 10years of B20 lifetime that will be 20% of the accumulated failure. Customers want refrigerators that have low energy and high reliability. Accordingly, the compressor redesigned to improve the efficiency of the refrigerator through statistical methodology or reliability testing before a product is launched. This study is to present a reliability methodology of the mechanical system subjected to repetitive pressure loading in a refrigerator. The reliability methodology includes:

a. A parametric accelerated life testing (ALT) plan,

b. A load analysis,

c. A tailored sample of parametric ALTs with the design modifications, and

d. Evaluating whether the final design(s) of the compressor achieves the reliability target. As a test, reciprocating compressors from French-door refrigerators returned from the field will study.

A. Reliability testing

i. Parametric accelerated life testing in compressor: The Compressor in the refrigerator increases the pressure of refrigerant by reducing its volume. Compressors are subjected to repetitive stress due to pressure loads. If there is a void in the structure where the loads are applied, the compressor will abruptly fail in its lifetime. After identifying the product failure by experiments, an engineer will design the compressor and material type to endure its own loads.

$$AF = \left(\frac{S_1}{S_0}\right)^n \left[\frac{E_a}{k}\left(\frac{1}{T_0}-\frac{1}{T_1}\right)\right] = \left(\frac{e_1}{e_0}\right)^\lambda \left[\frac{E_a}{k}\left(\frac{1}{T_0}-\frac{1}{T_1}\right)\right] \quad (1)$$

To obtain mission cycle of a parametric ALT, sample size equation with the AF can be expressed as [1]:

$$n \geq (r+1)\cdot\frac{1}{x}\cdot\left(\frac{L^*_{BX}}{AF\cdot h_a}\right)^\beta + r \quad (2)$$

ii. Case study: reliability design of a reciprocating compressor with a problematic suction reed valve from the field: The compressor takes refrigerant from evaporator, compresses it, and then delivers to the condenser. In this process, a reciprocating compressor increases the refrigerant pressure from that in the evaporator to that in the condenser. The suction reed valve allows the refrigerant to stream into the compressor.

French-door refrigerators returned from the field had no cooling. As a consequence, consumers had to replace their refrigerators because they no longer functioned. When the refrigerators returned in the field were disassembled, the fractured suction reed valve in the compressor was found. Scanning electron microscopy (SEM) also was used to inspect the suction reed valve failed in the field. The fracture started in a void in the valve and propagated to the end (Figure 1).

Based on the expected consumer usage conditions, we knew that the compressors were subjected to repetitive pressure loads due to normal refrigerator on/off operations. At right places, the problematic refrigerator compressors had critical design flaws. Thus, an engineer had to reproduce the failed compressor failures experimentally and correct them. To carry out the parametric ALT, the compressor was analyzed from the standpoint of the vapor-compression cycle. One

stress of a compressor system may come from the pressure difference between suction pressure, P_{suc}, and discharge pressure, P_{dis}. Another source is the compressor dome temperature. AF from Equation 1 can be redefined as

$$AF = \left(\frac{S_1}{S_0}\right)^n \left[\frac{E_a}{k}\left(\frac{1}{T_0} - \frac{1}{T_1}\right)\right] = \left(\frac{\Delta P_1}{\Delta P_0}\right)^\lambda \left[\frac{E_a}{k}\left(\frac{1}{T_0} - \frac{1}{T_1}\right)\right] \quad (3)$$

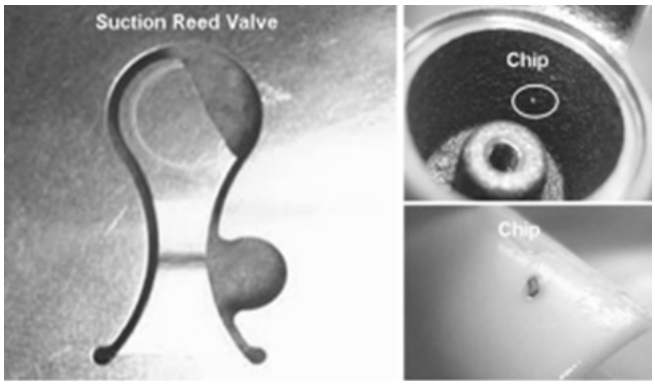


Figure 1 A damaged suction reed valve after use.

From the test data of the worst case, the differential pressure expected by the consumer in the operating compressor was 1.27MPa, and the compressor dome temperature was 90°C. To carry out accelerated testing, the compressor dome temperature was increased to 120°C and the differential pressure was almost doubled to 2.94MPa. With a cumulative damage exponentλ, of 2, the total AF was approximately 20.9. For the reliability target of 10years with an accumulated failure rate of 1%, the test cycles for 20 sample units calculated from Equation 2 were 38,300 cycles if the shape parameter was supposed to be 2.0. This parametric ALT was designed to ensure a B1 life 10years with about a 60% level of confidence that it would fail less than once during 38,300 cycles.

Results and discussion

In the first ALT, a compressor locked at 8,700 cycles. When the locked compressors from the field and first ALT were cut apart, suction reed valves fractured where they overlapped with the valve plate (Figure 2).

The root causes of the fractured suction reed valve came from the following improper designs includes:

a) Overlap with the valve plate;

b) A sharp edge on the valve plate

c) Weak material (0.178t).

These design flaws could cause the compressor to lock up suddenly when subjected to repetitive pressure loads (Figure 3).

To prevent the fracture on suction reed valve from the repetitive pressure stresses over the product's lifetime, the valve plate was redesigned as follows:

a) The trepan (see Figure 2(b)), C1, was increased from 0.73mm to 1.25mm

b) A ball pinning process, C2, was added to eliminate the sharp edge of the valve plate.

c) Additionally, the suction reed was redesigned as follows: the thickness of the suction reed valve (SANDVIK 20C), C3, was changed from 0.178mm to 0.203mm; the tumbling process time, C4, was extended from 4h to 14h to decrease the residual stress (Table 1).

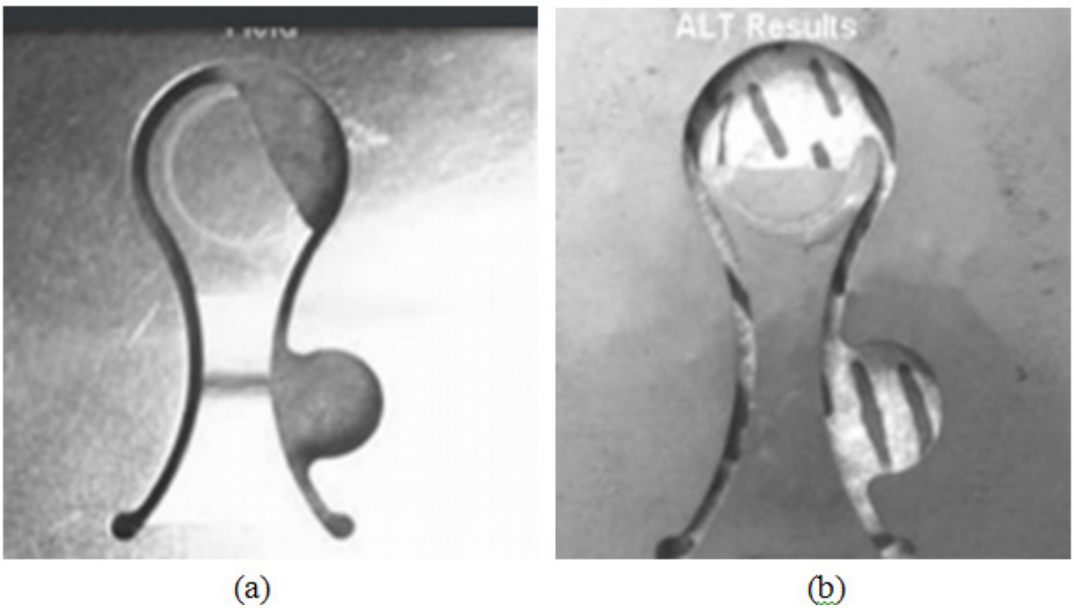


Figure 2 Failed suction reed valve products: a) the field; b) after the first ALT.

Citation: Woo S, Salilew WM, Teklay Y, et al. Reliability design of mechanical systems such as compressor subject to repetitive stresses. *MOJ Civil Eng.* 2020;6(1):12–15. DOI: 10.15406/mojce.2020.06.00165

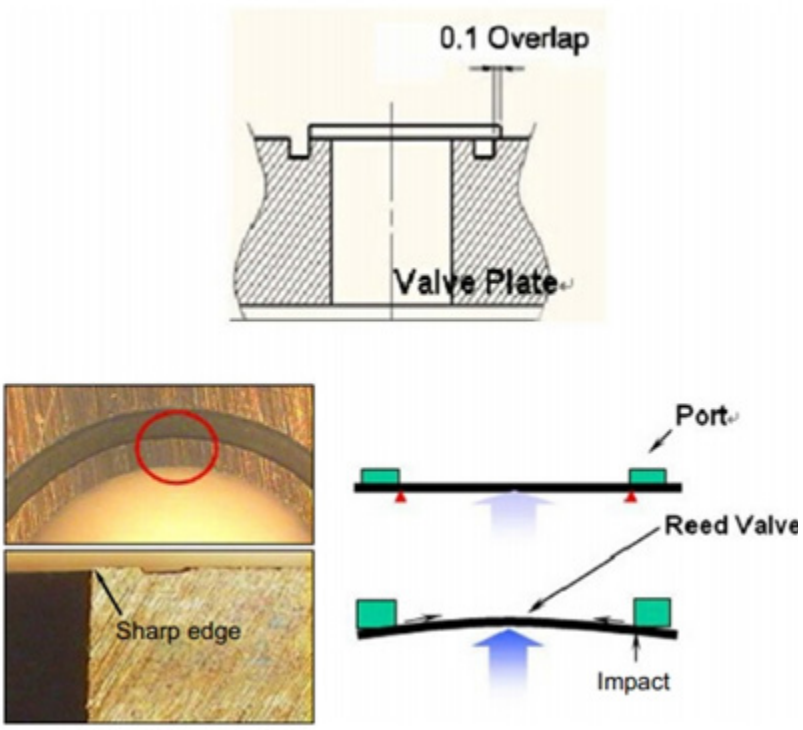
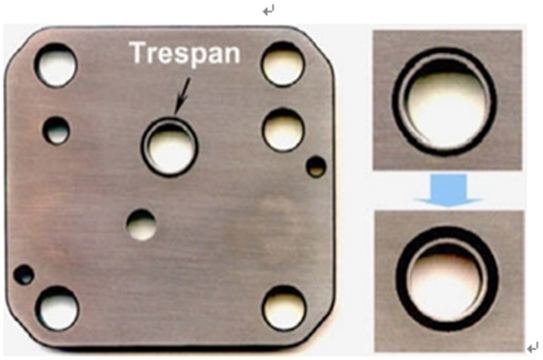
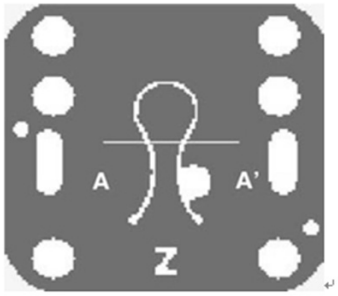
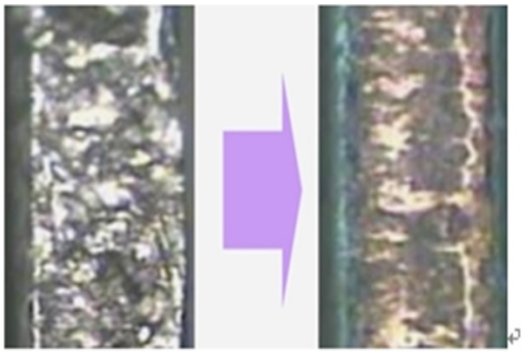


Figure 3 Failed suction reed valve products: a) the field; b) after the first ALT.

Table 1 Redesigned valve plate and suction reed valve

Valve plate	Suction read valve
	 Section A–A'
	
C1:Trepan:0. 73 mm ⟶ 1.25 mm	C3:0.178t ⟶ 0.203t (SANDVIK 20Cthickness)
C2:Ball peening and brush process	C4: Tumbling process time: 4 h ⟶ 14 h

Citation: Woo S, Salilew WM, Teklay Y, et al. Reliability design of mechanical systems such as compressor subject to repetitive stresses. *MOJ Civil Eng.* 2020;6(1):12–15. DOI: 10.15406/mojce.2020.06.00165

In the second ALT, there were no design problems of the compressor system until the test was carried out to 39,000cycles. We therefore concluded that the modified designs found from the first ALT were effective. Table 5 summarizes the parametric ALT results. With the modified design parameters, the final compressor system samples are guaranteed to achieve their reliability target of B1 life 10years. We also recommend this method for other compressors such as rotary screw compressors and rotary centrifugal compressors to improve their reliability.

Conclusion

To improve the reliability of the compressor in a French-door refrigerator, we developed the following reliability methodology:

a. Set the overall parametric ALT plan,

b. Carry out the parametric ALT with corrective action plans,

c. Check if the final compressor designs that satisfies the reliability target. As a test case, we studied the reliability design of a domestic compressor returned from the field.

In the field and the first ALT, the suction reed valves in the compressor were fracturing because of the following design flaws:

a) An overlap with the valve plate

b) A sharp edge on the valve plate;

c) Inadequate thickness of the suction reed valve (SANDVIK 20C0.178t).

As corrective actions, the trepan on the valve plate was increased from 0.73mm to 1.25mm and a ball pinning process was added to eliminate its sharp edge. As a result, there were no problems during the second ALT. The compressors were guaranteed to achieve the reliability target of B1 life 10 years. By inspecting returned products from the field and carrying out parametric ALT with action plans, the developed reliability methodology proves to be effective in improving faulty compressor system designs and ensuring the reliability criteria of final design were satisfied.

Acknowledgments

None.

Conflicts of interest

The author declares that there are no conflicts of interest.

Funding

None.

References

1. Woo S, Matvienko YG, O'Neal D. Improving fatigue of mechanical systems such as freezer drawer subject to repetitive stresses. *Engineering Failure Analysis*. 2020;110:104404.