Pressure Strength Test Requirements for Hermetic Refrigerant Compressor Housings Using Fatigue Analysis

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Abstract

The introduction of new refrigerants into the marketplace to replace CFC's banned by the Montreal Protocol has generated new research, required a review of many refrigeration concepts, and has raised new safety issues. One aspect that required further study occurred because some of the new refrigerants have a higher working pressure in the refrigeration and air conditioning equipment. This caused some research into the present safety factor used for pressure testing of equipment. Could this factor be revised or could a new method be developed using fatigue analysis to permit the new refrigerants to be used with current designs?

INTRODUCTION:

The Montreal Protocol and subsequent regulations involving CFC's in the USA have required considerable additional analysis of product designs. Additional information, protocols and regulations require increasingly complex evaluations of equipment in order to successfully bring the equipment to the market. New criteria were developed based on new concepts, including Ozone Depletion Potential (ODP), Greenhouse Warming Potential (GWP), and use of non-azeotropic (zeotropic) refrigerant blends.

Refrigerant manufacturers have responded by developing new refrigerants that perform adequately, at the same time striving for low or zero ODP, low GWP, improved efficiency, while still meeting the non-flammability requirement for refrigerants.

One of the leading candidate refrigerants proposed as a replacement for R-22, the refrigerant used in air conditioners and many commercial products, had higher pressures which could cause significant design changes in equipment based on the current safety requirements. Industry anticipated that these design changes would require stronger and/or thicker refrigerant containment materials, with the potential to reduce the thermal transfer of energy, resulting in a loss of efficiency. Since efficiency translates into increased greenhouse gas emissions (mainly carbon dioxide) this was considered undesirable.

Industry sought an opportunity to revise the safety requirements for pressure testing. The old well-worn rules were dusted off, reviewed, and required a complete reevaluation. However, an arbitrary reduction in a safety factor raised concerns about the potential for an increased safety risk. It was considered necessary to review the present safety requirements and determine whether an alternate scientific method could be developed to evaluate the characteristics of the materials as pressure containing parts.

ARI formed a task group from their membership and met over a two-year period to develop a new proposal. The task group reviewed the present safety requirements and the technical substantiation for the requirements, were given presentations on fatigue failure test methods as compared to burst pressure tests, reviewed other related standards, and proceeded to develop a proposal.

The task group defined their objective as 'to develop safety requirements based on technical substantiation that may be different than the current pressure test safety factor requirements while maintaining the level of safety associated with the current air conditioning and refrigeration products.'

PRESENT REQUIREMENTS:

The present safety requirements specify the burst pressure test criteria for a part containing pressure. This value has generally been established at five times the maximum expected normal pressure (or design pressure) or three times abnormal pressures (whichever is higher).

The design of a pressure containment system needs to consider the potential for rupture. Rupture may occur if the pressure exceeds the burst pressure of the containment system. Generally, a significant difference between the rupture point and the working pressure is sufficient to address potential fatigue failures. The rupture pressure limits can be determined by hydrostatic testing and/or material tests and analysis. Further system designs usually include self-limiting features and/or pressure relief devices so that it can be demonstrated that the burst pressure value will not be obtained under normal or abnormal operating conditions including external fire conditions.

Rupture can also occur as a result of material fatigue. In this case, rupture can occur at operating conditions or abnormal operating conditions due to stresses in the material caused by pressure and thermal cycling with the effects of stress cracking that may occur when continuously applying and relieving stress on a material. Bends, curved surfaces and the manufacturing process can also introduce internal high stress locations which can increase the potential for material fatigue.

SAFETY CONCEPTS:

The following safety concepts and related considerations are to be addressed by testing for burst or fatigue failure of refrigerant containment systems.

1) Refrigerant release which involves the following potential risks: a) Risks to atmosphere due to ozone depletion, and to the environment due to greenhouse warming; b) Risks to persons related to toxicity of the chemical or related to oxygen depletion in a defined space; c) risks to persons directly exposed to the leak with respect to potential contact with low temperature expelled liquid; d) risks to persons due to parts of the containment vessel that may be propelled due to a containment vessel rupture; e) risks to persons and property in the event an oil/refrigerant mixture is released and ignited; f) risks to repair personnel due to operating the equipment without various covers in place and under conditions required in repair and troubleshooting operations; g) risks due to loss of cooling or refrigeration and loss of property, business or adverse affects on persons including persons susceptible to conditions without the equipment cooling functions due to age, illness or location.

2) The present testing system and safety factor has an excellent field record that indicates it has reasonably addressed these risks with respect to the number of products employing refrigerant contained under pressure.

3) Risks are derived from the following sources. a) overpressure conditions due to overcharging, external fires, or other abnormal conditions; b) metal fatigue of the containment system that may result in a rupture even under normal operating pressures; c) damage to or weaknesses in the containment system that may reduce the material strength or increase the fatigue rate. Damage may be due to external impacts due to exposed locations during repair or installation, material defects or the securement of joints.

REVIEW OF RELATED ANSI/UL REQUIREMENTS:

The current pressure test safety factor evaluates the ultimate strength of the pressure containing parts, but it is not a method to directly evaluate fatigue failure. Based on the current field record, the requirement seems to have been set at a level sufficient for not conducting a fatigue analysis. An excellent field record for safety has been established for these products and components with respect to pressure containment. The field record therefore supports the present safety factor. Since there is not an established scientific relationship between ultimate strength and fatigue failure, it is therefore necessary to consider applicable aspects of a fatigue analysis and the impact on the safety evaluation.

It is recognized that design evaluation is generally conducted by qualified engineering personnel utilizing systems to develop designs adequate for product function and life expectancy. A fatigue analysis is often part of the design process.

In considering a proposed revision to the current safety factor, it may be necessary to establish the safety concerns and the minimum evaluation criteria to develop effective competitive designs that maintain at least the current level of safety. Evaluating only the safety factor testing included in other standards, organizations, or countries and/or other pressurized systems without full consideration into the design criteria may not be appropriate. In some standards, these tests and factors are in place as a continuing indicator that the design and manufacturing process has not changed in a manner that would adversely affect the design analysis (without having to requalify the design analysis periodically using a full level of qualifying tests). An example is the 1.5 times test factor applied to boilers as a final check of the system whereas the design criteria in the applicable boiler code is based on a significantly larger safety factor, a full understanding of the material properties under pressure cycling and temperature conditions, and a defined and qualified manufacturing and test process. This same principle is evident in other codes and standards.

THEORY:

Materials subjected to cyclic pressure are subject to cyclic stress conditions and at some point may exhibit a fatigue failure mode. The basic material property is identified by material testing and generally follows the curve shown in the attached graph (Figure 1). The graph is generated based on material specimens subjected to repeated stress until failure, at various pressures. A number of tests at various stress levels with a statistically selected number of samples are conducted on bar samples to establish the material characteristics and develop the curve on the graph.

The current safety requirements specify test samples of the actual part under one cycle condition and are shown as point (A) on the vertical axis. With a five times safety factor related to the maximum operating pressure, fatigue failures at normal operating pressures are apparently well within the expected number of lifetime cycles. This is based on the field record that has been established with at least 45 years experience with the refrigeration cycle and a very large number of products. In order to revise the safety factor, it is necessary to consider the relationship between the fatigue failure mechanism, the conditions under which the part is operated (pressure, temperature, number of cycles and failure mode) and the appropriate statistical test method.

APPLICATION OF THEORY:

The theory is generally applied by test to bar samples which may not fully represent parts constructed with various curved shapes or reinforced sections. A curve on the graph could be developed for each designed part but this would require extensive testing. To avoid extensive testing and to address actual parts, it is proposed to develop equipment parameters and develop test data to demonstrate that the part remains to the left side of the failure line on the graph without failure. The object of this testing would be to establish Line AB on the graph to demonstrate that the part does not reach the failure line under the operating conditions. The parameters are as follows and have been proposed in Standard UL 1995, Heating and Cooling Equipment.[1]

A) Number of Cycles - The number of cycles for parts was estimated based on the DOE test data developed for efficiency testing. It is noted that, compared to the "worst case" maximum number of cycles, the hotter (for cooling) or colder (for heating) areas will have fewer cycles per hour. Also, more temperate climates will have fewer cycles per year.

B) Test Pressures - The test pressures will be related to the equipment average operating conditions and the refrigerant used. The final part would be identified for its application with respect to design pressure.

The first cycle high test pressure was established as the maximum pressure the part was expected to experience under normal or abnormal conditions when used in the equipment. After the cycling conditions the part is then to be subjected to a pressure of 2 times upper pressure value of the cycling test or 1.5 times the marked or design pressure of the part.

C) Test Temperature - Since the fatigue line may be affected by the material and use temperature, the effect of temperatures is addressed by testing at a higher ambient if this value is reached in the equipment design.

D) Cycling Conditions - The exact method of pressure cycling the part was determined. The rise and fall times, the minimum and maximum pressure, the number of cycles per second, and other related test condition parameters that could affect the test are specified. It may also be necessary to consider the temperature and pressure excursions that may occur under some operating conditions (generally abnormal operation) in the conduct of the qualification test. The testing can be accomplished within a few days so that extensive test times are not specified.

The objective of this test would be to establish Line AB shown on the graph in Figure 1 to demonstrate that the part remains below and to the left of the failure line.

E) Number of Samples - Because of the testing variables and the statistical consideration, three samples will be subjected to the tests initially and periodically thereafter for follow-up requalification.

CONCLUSIONS:

The lower burst test safety factor combined with the fatigue analysis will provide manufacturers with an additional design tool. It may be possible that parts can be designed at critical points with respect to potential stress risers, and reduce the amount of materials where the material strength may currently be overdesigned. This would permit improved heat exchange (improved efficiency) and competitive designs without compromising the level of safety.

Reference:

(1) Underwriters Laboratories Bulletin Subject 1995 dated February 20, 1998

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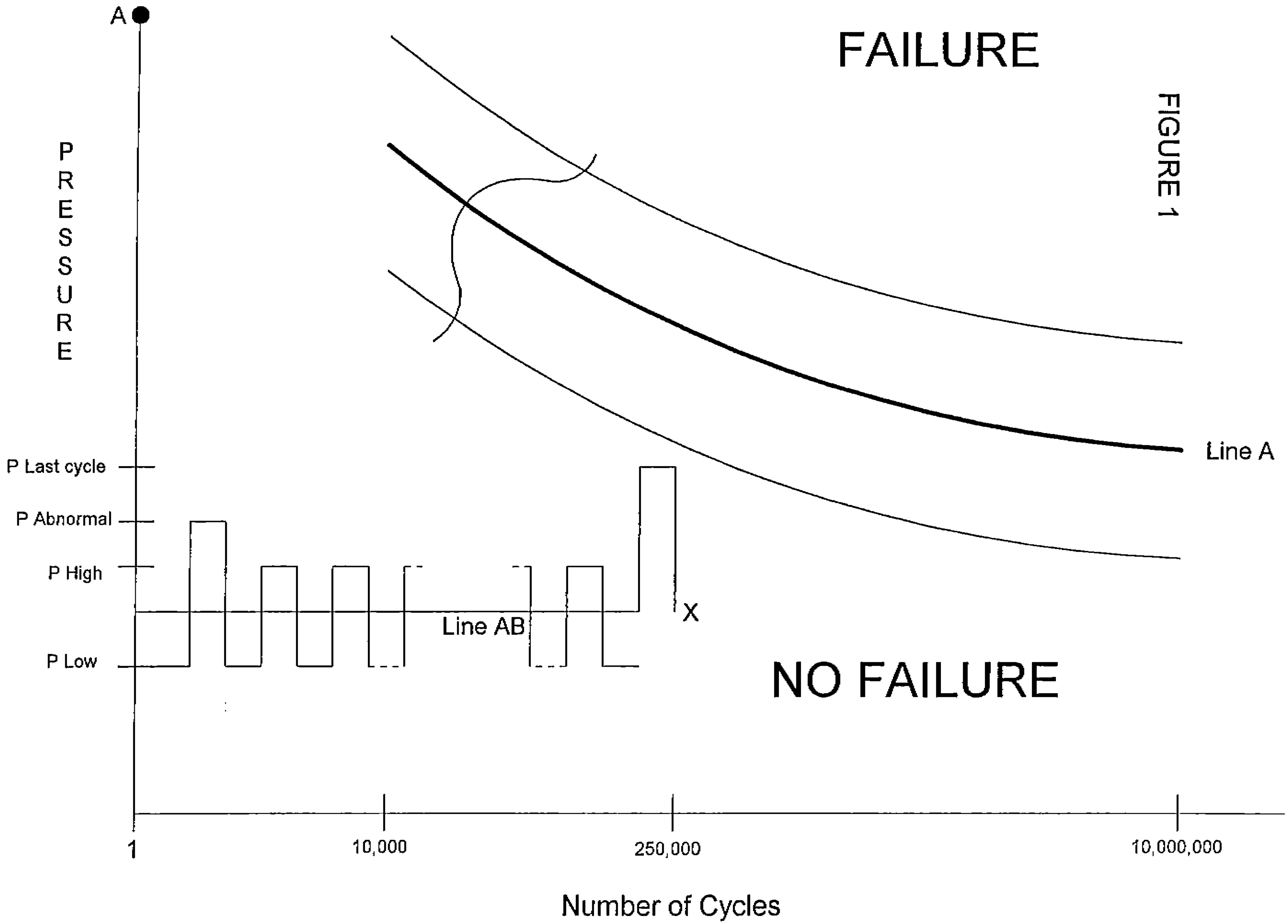
A
PRESSURE
FAILURE
Line A
P Last cycle
P Abnormal
P High
Line AB
X
P Low
NO FAILURE
1
10,000
250,000
10,000,000
Number of Cycles

FIGURE 1