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The Use of Weibull Analysis Methods in Assessing Field Failure Problems

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ABSTRACT

Unacceptable suction reed failure rates were occurring in a critical field application. Compressor failure resulted in excessive downtime costs, and extreme reliability was required in this application. A modified reed was placed into operation in a portion of the population. After a year's time failures were also occurring in the modified reed, although they were fewer in number. Sufficient field information with this new population was available to carry out a Weibull analysis. The analysis indicated an infant mortality problem was present, which was later found to be caused by the normal sub-surface microscopic inclusions in the reed steel. The analysis also indicated that completing the field campaign of the initial population would increase the probability of failure, and that no further changeouts should be made. It also indicated how much more improvement would have to made in a second reed modification to result in fewer failures compared to leaving the modified reed population in the field.

BACKGROUND

Particular installations of some semi-hermetic compressors require extremely high reliability of the compressor to prevent downtime of a major system. Downtime of some systems can result in very high financial penalties to a customer, at times as high as $50,000 per hour. In situations like this the compressor manufacturer can be certain that he will be informed of any failures, and requested to prevent future failures of the same type. One benefit of an occurrence of this nature is that fairly reliable data is available concerning the field failures and statistical analysis can be carried out to predict what future action should be taken to minimize any further customer disruptions.

A situation of this nature occurred in the early 1990's, and Weibull techniques proved invaluable in the decision process involved in solving the problem.

About 250 compressors of a given type had been placed in the field. After some time in service it was determined that the suction reed failure rates were too high and the customer demanded that improvements be made. Strain gage testing indicated that the suction reed stresses were indeed too high under the particular operating conditions for that customer, and the reed was increased in thickness to reduce the stress levels, to what was thought to have been a conservative value. During 1990, 150 compressors were field fitted with the new reed configuration. One hundred compressors remained unchanged, with the original reed configuration.
By the end of 1991 three of the new, reduced stress level reeds had failed, and the customer was adamant in demanding a further change. Record keeping had improved by that time, and reliable "time to failure" data was available. The three times to failure were 8 hours, 500 hours and 1000 hours. This data was plotted on Weibull paper using standard Weibull techniques, and the results can be seen in Figure 1. It was immediately apparent that the Weibull slope was well below one, which indicates an infant mortality problem. At the same time, metallographic examinations of the failed reeds indicated that the failures all started at sub-surface microscopic inclusions, in high tensile stress areas, located near the surface of the reed.

These inclusions were of a size that can be normally expected, even in a very clean valve steel, and were within the specifications for the material. It became apparent that the failures were a result of the stress concentrations caused by the presence of these inclusions, and that the inclusions had to be present in a high tensile stress area of the reed, in order for a crack to be initiated and propagated. The combination of a rare inclusion in a highly stressed volume of the reed (which is also a relatively small percentage of the overall reed volume) caused a valve failure. The particularly severe requirements for high reliability of this particular application resulted in the discovery of these low probability circumstances.

At the time the analysis was started there were 150 compressors in the field with the new reed. It was estimated that the time on those compressors was about 7000 hours. There were also 100 compressors in the field with the old, more highly stressed reed, and
these were estimated to have about 16,000 hours. The expected life of the total system was around 24,000 hours, at which time it would be replaced.

In order to predict what would happen to the entire population of 150 a "Dauser Shift" (Reference 1) was applied to the original Weibull line, using the following technique:

* The current failure rate was estimated at 2% (3 failures divided by 150 operating compressors)
* The mean time to failure was estimated by adding the hours to failure of each failed compressor and dividing by three
* This point was then plotted on Weibull paper, and a line passed through that point with a slope of that of the original three failures.

This plot then becomes a means of predicting what will happen to the remaining compressors in the field. The slope of the original failures is, of course, critical to the accurate analysis and the more points one has to determine that slope, the higher the confidence level in the analysis. However, in situations of this nature, very limited amounts of data are likely to be available.

Figure 2 is the resulting shifted Weibull plot. One comforting fact was immediately apparent. At the time the analysis was carried out, the compressors had around 7000 hours. At the 7000 hour mark, it can be seen that a 5% to 6% failure rate should have occurred. This would indicate that 8 failures should have occurred by that time.
Since there were no further indications of failures, it was concluded that we were conservative in our estimates, and that the actual slope was lower than that predicted by the original three failures. Figure 2 also shows that by the end of 24,000 hours we could expect a failure rate of around 8% to 9%, or a total of 13 compressors. In other words we could expect at least 6 more failures in the next 17,000 hours operating time.

Figure 3, which is a cumulative distribution plot, illustrates the same information more clearly.

One of the more important questions to be resolved was should we continue the field campaign of the remaining 100 compressors with the original higher stressed valve. Strain gage tests had indicated that we had reduced the stress levels by about 15% when making the reed modification. With this information, a Weibull line could be constructed for the old reeds, if one can assume that the Weibull slope for the old reeds is the same as the modified reeds. The mechanism causing the infant mortality problem was considered to be the same for the original reed is the modified reed, and it was concluded that the slope should also remain the same.

Since the difference in stress levels is known for the two different reeds, the time to failure for the old reeds can also be estimated, by using information available from the material S-N curve and finding the equivalent times to failure.

If this is done the Weibull plot shown in Figure 4 can be established and the cumulative failure plot (Figure 5) drawn. Since the compressors with the old reed had 16,000 hours it can be seen that the failure rate should be about 18%, or 18 failures could have been expected. This was indeed close to the number that was thought to have failed (accurate data was not available).
More importantly, the failure rate after 24,000 hours is 20%, or 20 units. Thus, only two more units could be expected to fail in the remaining time that the compressors would be utilized.

However, if the compressors were campaigned with the new reed, an 8% failure rate (8 compressors) could occur in the remaining 8000 hours of compressor life, since we would be starting out with a new population of reeds. Thus, it is unwise to campaign the 100 compressors that remain in the field. The compressors that had inclusions in the highly stressed volumes have already failed, and those that remain are safe and need not be changed out, since they have been "screened" by this time.

The next question to be answered was how much does the reed stress have to be reduced from the modified reed to warrant a field campaign of the 150 compressors with the modified reed. Since in the remaining 17,000 hours of useful compressor life less than 6 failures are desired (only 6 more
Compressors will fail without a campaign; a new line can be established (Figure 6). Again, using material properties from the S-N curve it can be deduced that at least a 10% reduction in stress had to be realized. It was determined that this could not be done without seriously compromising the performance of the compressor, so the decision was made to not make any further modifications or field campaigns.

Since the time this analysis was carried out, two additional failures have occurred in the modified reed design, one at 3600 hours and another at 8000 hours. This information was added to the initial failure information and reinforced those decisions already made. As of this time there have been no further failures of either the modified reeds or the original designs.

CONCLUSION

Weibull analysis methods have been successfully utilized to predict the number of failures that would occur in compressors in the field. Weibull techniques avoided a costly field retro-fit program which would have introduced additional failures in a critical field operation. These techniques can be applied with a minimum of data, and conservative approaches can be taken.

References: "The New Weibull Handbook", Dr. Robert B. Abernethy, Author and Publisher, 536 Oyster Road, North Palm Beach, Fla. 33408.