Try Statistical Failure Analysis.

It cannot be stated often enough that equipment reliability is intimately tied to our willingness and ability to analyze failure incidents as they occur. One of the tools which we should be familiar with is statistical analysis. It will help us to describe the failure pattern of our machinery population – provided the necessary data is available.

One of the most powerful statistical failure analysis method is Weibull[1] analysis. This is a mathematical formulation which represents the various portions of the failure rate curve shown in Figure 1 and in its simplest form looks like:

$$\text{Probability of Failure} = 1 - e^{-\left(\frac{t}{\eta}\right)^{\beta}}$$

where
t = time in service
η = scale factor or characteristic life
β = Weibull slope

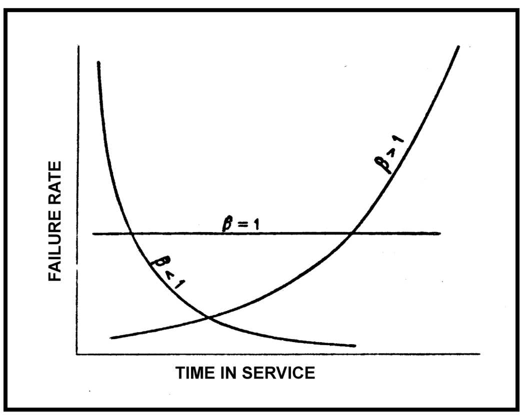


Fig.1. The relationship between the value of β and the shape of the failure rate curve

While we shall not bother the reader with more mathematical theory we must dwell on the significance of the Weibull slope just mentioned. It is eminently important to know this value as it applies to a specific popopulation of failing parts, components, or machinery units. Why? Because it tells us something about the maintenance strategy we must apply to improve equipment reliability.

$\beta < 1$ corresponds to the curve in Fig. 1 for failures involving some initial defects, i.e. a sign of infant mortality. The failure causes may be found in design, manufacturing, operations and maintenance in terms of:

- The equipment seems unsuitable for the service in the first place.
- Misassembly and quality control difficulties
- Start-up procedures and mal-operation
- Overhaul and repair problems

$\beta = 1$ represents the intermediate region. It implies random failure experience with frequently random causes. Our maintenance strategy should be positively predictive maintenance (PdM) with hardly any planned periodic overhauls, repairs or interventions. "Overhauls are not appropriate. An old part is as good as a new part because of chance failure occurrences"[2]. Typically, anti-friction bearings and mechanical seals fall into this category as well as centrifugal pumps in relatively clean fluids. Other systems contain fail-to-danger components that fail when they are activated required to function. Here is where periodic testing as a function of failure frequency is indicated.

$\beta > 1$ corresponds to the curve for wear out failures. 1 < Weibull slope < 4 implies **early** wear out because of:

- Low cycle fatigue
- Premature bearing failures
- Corrosion or erosion

Here overhauls or part replacements may be cost effective. A good example

[1] Waloddi Weibull – Swedish mathematician. "A Statistical Distribution Function of Wide Applicability", **Journal Of Applied Mechanics** ASME Paper—**1951.**

[2] See Paul Barringer at www.barringer1.com

would be the valves on reciprocating compressors.

β > 4 implies old age and rapid wear out because of:

- Material property problems
- Brittle material problems as they occur with ceramics
- Some forms of corrosion and erosion.
- The component is not fit for purpose.

In this case, the maintenance strategy should be redesign or planned equipment replacement if the life expectancy of the component or equipment is considered as being too short; another approach would be to develop cost-effective overhaul and replacement intervals. In our next column we will show how this is accomplished.

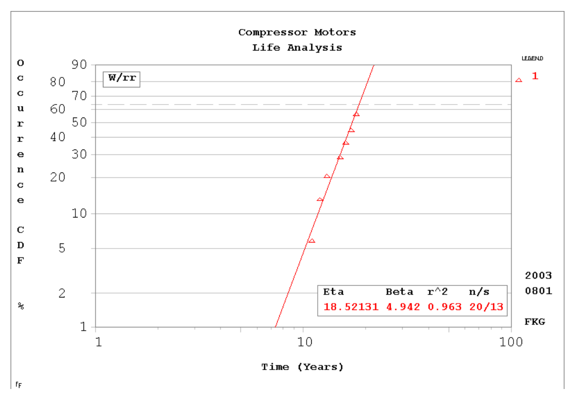
A convenient way of arriving at Weibull Parameters is to plot field data in form of "lives", i.e. operating times to failure. This relates the time in service to the cumulative percentage failure rate, that is, the total number of parts, components or pieces of equipment which have failed in a given time as a percentage of the number that have been in service at that time. This sounds complicated, but usually there is no requirement for tedious calculations as computer programs[3] allow us to bypass all this. What we need are time-in-service intervals as shown in Table 1. The years marked "X" represent actual times to failure of large electric motors (> 1,500 hp and up) driving pumps and compressors in a petrochemical plant. The data not marked "X" represent actual running time – without failure – to the time the "snapshot" of Table 1 was taken. In the Weibull distribution these unmarked times are called censored or suspended times and are used in the plotting procedure. There is one requirement for the data: It must originate from a reasonably homogeneous population, i.e. same function, size, vintage and basic construction features.

The life experience of the motor population in Table 1 is plotted in Fig. 2 showing a characteristic life of 18.5 years but, more important, a Weibull slope (β) of 4.9 as an indication

Table 1.

Motor	Years to Failure
C-70	8
C-71A	8
C-71B	8
P-70A	8
P-70B	8
P-71	8
C-25	10
C-11	11X
C-52	12X
C-13	13X
C-31	13
C-53	15X
C-41	16X
C-91	17X
C-32A	17
C-32B	17
C-01	18X
C-30	18
C-50	18
C-51	18

X = Winding Failure



CDF = Cumulative Density Function
r^2 = evaluation of goodness of fit, i.e. good correlation to Weibull distribution
n = number of lives
s = number of suspensions

Figure 2. Weibull plot.

of severe old age wear out. This suggests that it would be prudent to replace motors referred to in Table 1 after say, 15 to twenty years on a

[3] WINSMITH WEIBULL® - See note 2

planned or preventive basis because by age 22 – as the plot shows – all of them will have most probably failed. Let this be a preliminary conclusion – until we meet again reading the next column.

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