CHAPTER 7

DERATING

CONTENT

1. INTRODUCTION

1.1 Derating is a design process that can make a significant contribution to reliability. This chapter describes policies and methods for derating electronic components and mechanical systems equipment.

1.2 Derating is defined as ‘a policy of deliberately under stressing components in order to provide increased reliability’. The selection of components of higher stress capability than is required for normal operation is an empirical but effective and well established method of reducing their failure rate; e.g. the use of a half watt resistor in circuit conditions demanding a quarter watt dissipation.

1.3 Stress rating is defined as the ratio of applied stress to rated stress, for example, the ratio of applied voltage to rated voltage in capacitor applications. Generally as stress increases failure rate also increases, usually exponentially; conversely as stress reduces failure rate reduces. However, care must be taken when applying derating as a method of improving reliability because at very low stress ratios failure rate may again increase.

1.4 Typically the components to which derating is applicable include transistors, resistors, transformers, integrated circuits, micro-electronic devices, and other passive electronic devices with stress dependent failure rates, such as capacitors and inductors.

1.5 History shows that a significant number of equipment failures arise from inadequate design margins. The derating factors listed for electronic equipment in Table 1 should not only ensure that components are operated well within the recommended limits of stress, but also provide in most cases a sufficient design margin to accommodate minor variations in environment stress, power supply levels, transients, etc.

1.6 Failures caused by stress transients in the operational environment are in fact often due to inadequate design margins. Test conditions seldom reproduce these transients, and failures of this kind are, therefore, difficult to diagnose in the field. Derating can eliminate many such potential problems.

1.7 Electronic components are in general subject to at least two stresses, an electrical stress, with increasing tendency to breakdown due to voltage, current or power and a thermal stress due to its own power dissipation and, in part, to the total dissipation of neighbouring components and/or the local environment. Reducing electrical stress will indirectly reduce thermal stress and lead to improved failure rates.

1.8 Failure rates for generic component types invariably assume that the failure rates are constant with time and that the components are conservatively rated. Thus predictions based on component count procedures pre-suppose that derating will be applied.

1.9 The methods described in this chapter are aimed at reducing failures by increasing design margins, i.e. the margin of design strength over expected stress. To make an impact on the overall system failure rate a derating policy must be applied to as many components as possible. In some cases this may incur weight or space penalties; however, such cases should not prevent the policy being applied as far as practicable.

2. AVAILABLE METHODS FOR DERATING ELECTRONIC COMPONENTS

2.1 Derating information is published in various forms and may be provided as:

a) Mathematical models containing a stress derating factor for calculating component failure rates.

b) Graphs relating stress to percentage of maximum rating, providing a design envelope within which components should be operated (see Figure 1).

c) Sets of graphs relating stress to percentage of maximum rating, which provide alternative design envelopes for component operation with acceptable, questionable and restricted zones.

d) Individual derating factors for each component type related to one critical stress condition.

2.2 Derating characteristics which relate a critical environment to the percentage of maximum rating are sometimes available in component manufactures application data sheets. A typical derating curve for a transistor is illustrated in Figure 1. This derating characteristic shows that there is a significant benefit in reducing the applied voltage stress levels. This is most noticeable as the junction temperature rises. Junction temperature is driven by ambient temperature, the thermal resistance between the junction and the case and the power dissipation of the transistor. Operating within the design envelope of the transistor achieves a degree of derating which is desirable, and conversely, operating beyond the design envelope incurs a degree of overstress that should be avoided.

2.3 Use of these mathematical models and graphs implies that the true operating environment is known. In most cases in the design stage it is unlikely that this would be true since it is very difficult, time-consuming and expensive, although not impossible, to obtain this information for every component. For these reasons a single value derating factor for each part type, related to its significant stress condition, is recommended, see Table 1 below, except where a detailed thermal and stress analysis is applied.

3. APPLICATION OF DERATING FACTORS (ELECTRONIC)

3.1 The significant stress to be derated is particular to each generic part type and its failure mechanism. In the case of semi-conductors it is generally the power that is derated to control the junction temperature. In capacitors it is the voltage stress for a given temperature on the dielectric that is critical. In relays it is the current density at the contacts, and in RF transistors it is again current density that is critical, while in digital integrated circuits it is the degree of fan-out[1] that is critical.

3.2 Recommended derating factors, which will ensure a sufficient design margin in most applications are summarised in Table 1. In cases of particularly critical components or special circuit conditions the component manufacturers' derating characteristics are to be used.

[1] Fan-out' is the number of digital elements driven by the output stage of a particular digital device.

Component Type	Parameter Derated	Derating Factor (%)
Resistor	Power	80%
Resistor Variable	Power	75%
Transistor	Power	75%
Diode	Voltage	50%
Diode Signal	Voltage	85%
IC Linear	Current	85%
IC Digital	Fan-out	80%
Thermistor	Power	50%
Capacitor	Voltage	75%
Transformer	Power	80%
Relays	Contact Current	50%
Switches	Contact Current	50%

Table 1 - Recommended Derating Factors

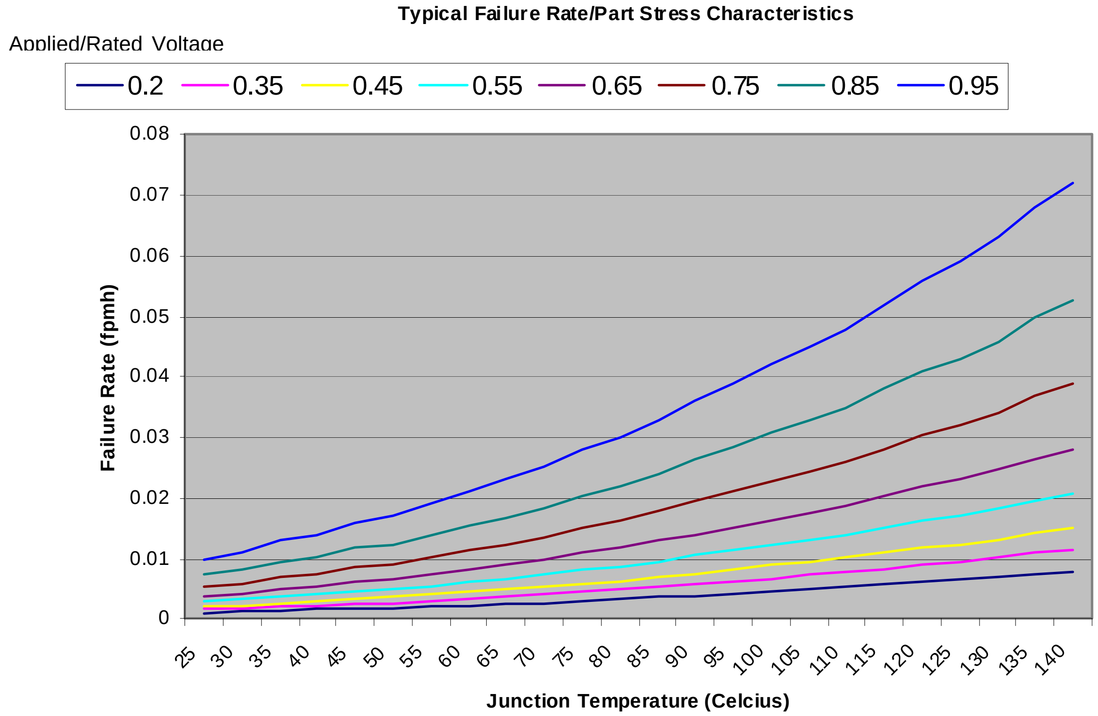

Figure 1 – Typical Derating Characteristic for a Bipolar Transistor

3.3 For component types not listed in Table 1 above the manufacturer should be consulted for recommended derating factors.

3.4 Derating components to improve equipment reliability must be conducted with due regard to specified minimum operating conditions, e.g. a minimum safe polarising voltage for electrolytic capacitors.

4. DERATING OF ELECTRICAL AND ELECTRONIC COMPONENTS

4.1 General

4.1.1 The reliability of electronic components decreases when they are operated at high stress levels. These stresses are primarily temperature, voltage, current and power dissipation. Heat-generating components in particular, such as transistors, resistors, valves and transformers, are susceptible to these stresses which result in degraded performance and accelerated failure.

4.1.2 The problem is one in which the materials employed in the construction of the component have upper and lower temperature design limits, beyond which performance changes develop or catastrophic failures occur. This problem can be brought under control by ensuring that the component functions within its design rating. It is mostly a heat balance problem and can usually be solved by keeping components cool enough to function reliably.

4.1.3 The theoretical justification for derating is discussed as a means of reducing thermal and electrical stress, and derives two mathematical models relating component failure rates to stress conditions.

4.2 Temperature Stress

4.2.1 Under normal operating conditions, a component is considered to have failed when its design parameters have changed beyond the limits of its acceptance specification, due to degradation processes. In a structurally sound component most processes of degradation are primarily dependent upon chemical reaction and include such phenomena as hot spot formation. increased carrier generation, parametric degradation, aluminium migration, gold-aluminium interdiffusion.

4.2.2 In 1889 Arrhenius suggested an empirical model for the rate at which chemical reactions occur at different temperatures. The Arrhenius chemical reaction rate law is:

$$\text{Chemical Reaction Rate} = \text{A} \exp - \left(\frac{E}{RT}\right) \quad \ldots\ldots\ldots\ldots \quad \text{(i)}$$

where: A is a constant;

E is activation energy;

R is Boltzmann's gas constant;

T is absolute temperature**.**

4.2.3 Where it is assumed that failure rate is directly proportional to chemical reaction rate, the failure rates to be expected at different temperatures can be estimated, e.g.

Failure rate at temp (T) = λ = B exp (-E/RT) . . . . (ii)

where: B is a constant which relates failure rate to exp(-E/RT)

E is the activation energy in electron-volts which is assumed constant

R is Boltzmann's gas constant 8.63 x 10 $^{-5}$ eV/Kelvin

T is temperature measured in Kelvins at which the failure rate (λ) is required

4.2.4 If To is a temperature with which a 'known' failure rate (λ o) can be associated, then:

$$\frac{\lambda}{\lambda_0} = \frac{B\exp(-E/RT)}{B\exp(-E/RT_o)} \qquad \text{(iii)}$$

$$\therefore \quad \frac{\lambda}{\lambda_o} = \exp\left(\frac{E}{R}\left(\frac{1}{T_o} - \frac{1}{T}\right)\right) \qquad \text{(iv)}$$

4.2.5 The relationship between failure rate and temperature can be seen from equation (iv).

4.2.8 This approach assumes that the reaction rate of the failure mechanism is related to degradation time and therefore to component failure rate. However, the activation energy of a particular failure mechanism is not the same as the apparent activation energy to reach some limit of parameter variation, since several failure mechanisms may be operating at the same time to produce one apparent component failure activation energy.

4.2.9 Where a single failure mechanism is considered, a reliability analyst may attempt to determine the apparent activation energy (E) of that failure mechanism using time to failure data from a suitable sample. A graph of time to failure against the reciprocal of temperature, using Log/Linear graph paper, will result in a straight line (the Arrhenius Line) when the theory applies, and the activation energy that is sensibly constant for each failure mechanism, can then be determined from the slope of the line.

4.2.10 Supposing that:

To = 288K (15oC) and T= 303K (30oC)

and, assuming a value for the apparent activation energy;

E of approximately 1 Volt (say 0.92V), then $\lambda = 2\lambda_o$

This implies a doubling of failure rate for an increase of 15^{o}C or, conversely, a halving of failure rate for a decrease of 15^{o}C for the example chosen.

4.2.11 Typically failure rates change by a factor between 1.1 and 2.0 for a change of temperature of 15oC, the higher factor being applied to transistors and some capacitors and the lower factor being appropriate for resistors. In general the relationship between failure rate and temperature is that given by equation (ii), i.e. failure rates increase exponentially as temperature increases. This effect can be seen in Figure 1.

4.3 Electrical Stress

4.3.1 Items such as capacitors that are subject to voltage stress also need to be derated to reduce failures due to dielectric breakdown. It has been suggested that failure rate is related to dielectric stress by a 5^{th} Power Law, which states that life of an item, i.e. its mean time to first failure, is inversely proportional to the fifth power of dielectric stress.

4.3.2 Taking a more general view, the relationship can be stated in the form of an nth power law, and since failure rate (λ) is the reciprocal of mean time to first failure then (λ) is proportional to dielectric stress (S) to the nth power.

$\lambda = AS^n$, where A is some constant . . . . (v)

when, S_o is a stress with which a 'known' failure rate λ_o can be associated, from (v)

$$\frac{\lambda}{\lambda_o} = \frac{S^n}{S_o^n}$$

$$\therefore \quad \lambda = \lambda_o \left(\frac{S}{S_o} \right)^n \quad \ldots \ldots \ldots \ldots \quad \text{(vi)}$$

when, n is a constant, which typically has a value of 5.

4.3.3 Supposing that S is 100V, So is 87V and n = 5

$$\lambda = \lambda_o \left(\frac{100}{87} \right)^5 = 2\lambda_o$$

This implies a doubling of failure rate for a 15% increase in dielectric stress for the example chosen.

4.3.4 Data sources that relate failure rate to stress can show that the failure rates do not generally indicate such drastic changes, suggesting that perhaps a fifth power law is pessimistic for many individual component types and also may not apply for stress ratios less than 0.5. In general the relationship between failure rate and voltage stress is that given by equation (vi), i.e. failure rate increases according to a power law as stress increases.

4.4 Resisters

4.4.1 Given that resistors are properly made, the two principal influences on component failure rate are temperature and electrical stress. Derating characteristics for resistors specify a maximum stress for these two critical parameters by limiting the power dissipated.

4.4.2 The power rating of resistors is dependent upon the manufacturing techniques and materials used, and limited by a maximum hot-spot temperature. The power that can be developed in a resistor body depends upon how effectively the dissipated energy is carried away and is therefore a function of the local temperature and heat transfer conditions. At all temperatures above the rated temperature for the type, resistors should be derated.

4.4.3 The following electrical stress ratio for derating resistors is recommended:

$$\text{Stress Ratio} = \frac{\text{Operating Power}}{\text{Rated Power}} = 80\%$$

This recommended stress ratio provides a sufficient design margin in most practical cases and in addition increases resistor stability.

4.4.4 For variable resistors the operating current in any part of the resistor is the critical stress condition. The stress ratio for variable resistors is given by:

$$\text{Stress Ratio} = \frac{\text{Operating Power}}{\text{Rated Power}} = 75\%$$

In this case the derating factor is more stringent than that for fixed resistors since variable resistors have, in general, a higher failure rate than fixed resistor types and a greater design margin is needed.

4.4.5 Power is not, however, the only quantity in which stress ratings are specified. For example, a resistor may be rated at 300mW dissipation in free air at 20^{o}C, or the same type may be rated at 250V d.c. across the resistor. In every case the ‘limiting element voltage’ specified for the type must not be exceeded.

4.5 Semi-Conductor Devices

4.5.1 Transistors

4.5.1.1 Transistors can be destroyed by exceeding the manufacturer’s voltage rating even for a few micro-seconds. Transient voltage spikes of comparatively small magnitude and very short duration are very difficult to trace and can often be the reason for circuit failures which appear to have no obvious cause. In terms of power, transistors are rated in a similar fashion to resistors, except that the limiting hot spot occurs at the junction, and junction temperature is the most important parameter.

4.5.1.2 In practice it is essential to derate transistors to a level which ensures that the manufacturer’s recommended junction temperature will not be exceeded. To this end, the following electrical stress ratios are recommended as a minimum:

$$\text{Stress Ratio (1)} = \frac{\text{Operating Power}}{\text{Rated Power}} = 75\%$$

where, operating power is the power dissipated in the device.

$$\text{Stress Ratio (2)} = \frac{\text{Operating Vge}}{\text{Rated Vge}} = 90\%$$

where, Vge is the voltage between collector and emitter.

$$\text{Stress Ratio (3)} = \frac{\text{Operating Ic}}{\text{Rated Ic}} = 90\%$$

where, Ic is the collector current. Each of these ratios must be complied with at the same time in each particular transistor application.

4.5.2 Power Diodes

The following stress ratios are recommended for power diodes in order to ensure, in general, that the limiting junction temperatures are not exceeded:

$$\text{Stress Ratio (1)} = \frac{\text{Operating PIV}}{\text{Rated PIV}} = 50\%$$

and,

$$\text{Stress Ratio (2)} = \frac{\text{Operating If}}{\text{Rated If}} = 70\%$$

where, stress ratio(1) is the peak inverse voltage derating factor and stress ratio(2) is the forward current derating factor.

4.5.3 Small Signal Diodes

4.5.3.1 The following stress ratios are recommended for small signal diodes in order to ensure, in general, that the limiting junction temperature is not exceeded:

$$\text{Stress Ratio (1)} = \frac{\text{Operating PIV}}{\text{Rated PIV}} = 85\%$$

and,

$$\text{Stress Ratio (2)} = \frac{\text{Operating If}}{\text{Rated If}} = 85\%$$

4.5.3.2 Each of these stress ratios must be complied with at the same time in every application.

4.6 Transformers

4.6.1 The policy and principles for the derating of transformers applies also to similar devices including inductors, chokes, magnetic amplifiers and RF coils.

4.6.2 Most transformer failures result from insulation breakdown and resulting short circuit, and the overheating that follows may result in misshapen or burst containers due to expansion of the potting or filling compound. Open circuit windings occur only occasionally.

4.6.3 Transformer failures are largely due to the insulation becoming brittle and losing its insulation qualities. This is usually caused by hot-spots and is related to the operating temperature. The operating temperature in turn is related to the power dissipation of the device and the operation stress ratio.

4.6.4 The operating temperature of transformers can be estimated as follows:

> Operating Temperature = ambient + 0.15 of Rated Temp on full load + (0.85 of Rated Temp x Stress Ratio)

Note: All temperatures are in degrees Celsius.

4.6.5 The following electrical stress ratio is recommended for transformers and similar devices:

$$\text{Stress Ratio} = \frac{\text{Operating VA Load}}{\text{Rated VA Load}} = 80\%$$

4.6.6 This stress ratio will, in most cases, ensure that the limiting hot-spot temperature is not exceeded.

4.7 Capacitors

4.7.1 Capacitors in general do not dissipate heat in the same way as resistors, transistors or transformers, except when they are subjected to ripple currents or pulse loads when derating does become important. However, they are subject to thermally sensitive failure modes that depend on the materials used in their manufacture.

4.7.2 Some of the principal conditions associated with capacitor failure are current overload, voltage overload, high frequency effects, high temperature, high pressure, humidity and shock. The most important of these are voltage and temperature stress, which are the principal factors to be derated.

4.7.3 Dielectric breakdown may occur after many hours of satisfactory operation and is associated with a slowly changing physical or chemical reaction. The ultimate failure is, however, most often associated with one abnormal electrical or temperature stress.

4.7.4 The recommended electrical stress ratio for all types of capacitor is:

$$\text{Stress Ratio} = \frac{\text{Operating Voltage}}{\text{Rated Voltage}} = 75\%$$

4.7.5 In all cases the capacitor selected for a particular application must be carefully chosen from the various types available to avoid misapplication. A significant number of equipment failures are due to incorrect selection and application of capacitors.

4.7.6 Electrolytic capacitors are a special case and have power factors several times higher than other capacitor types and due to 'leakage' currents which cause significant self-heating. This self-heating tends to increase with age and can build up causing complete failure, thus derating is particularly important. Non-electrolytic capacitors can be derated down to 10% of the maximum voltage rating, though this is seldom physically practicable; however, this is not true for electrolytic capacitors which may exhibit increased failure rates at these low levels because a minimum voltage is required to establish and maintain the polarisation of these types. The principal derating parameter is 'surge voltage' for solid tantalum types and 'ripple current' for other electrolytic types. These capacitors must not be operated below the minimum specified voltage; they should be derated but still comply with the manufacturers minimum requirements.

4.8 Micro-Electronic Circuits

4.8.1 This heading includes Integrated Circuits, Medium Scale Integration (MSI) Circuits, Large Scale Integration (LSI) Circuits, and Hybrid Circuits, and covers both thick and thin film technology.

4.8.2 In any given type of micro-electronic structure the device reliability is very strongly related to temperature of operation, and particularly to junction temperature in applications where the power dissipated in the device is relatively high. The heat generated must be dispersed using appropriate metal or ceramic packaging.

4.8.3 The specific stress ratios are necessarily different for each type of device and the only generalisations that can be made are that digital IC's should be derated in terms of fan-out and linear IC's in terms of current. The following derating factors are recommended:

Digital Integrated Circuits	Fan-out	80%
Linear Integrated Circuits	Current	85%

4.9 MOS Devices

4.9.1 The predominant cause of failure in MOS and C-MOS devices is electrical overstress; experience with C-MOS devices under test conditions indicated that over 40% of failures arise from this cause. The overstress can be due to mishandling since these devices are especially sensitive to static discharge, and this has been found to be the most frequent cause of failure. Precautions to be taken to protect expensive devices from static damage include:

a) Avoid handling a device by its pins.

b) Use conducting foam to protect pins and provide a leakage path.

c) Avoid static discharge from operators' clothing.

d) Provide conductive paths for workbenches and stools in assembly areas.

4.9.2 MOS and C-MOS devices typically operate at supply voltages ranging from 3V to 18V. The choice of supply voltage influences the speed of operation, because the higher the voltage the shorter the rise and fall times of the output pulses. However, increased supply voltage also increases the power consumption and thermal dissipation, and directly influences the failure rate. Manufacturers' life tests of MOS devices indicate an increase in failure rate of at least 10 times for an increase of supply voltage from 10 to 15 volts, and it is clear that a compromise between operating speed and reliability has to be made. Thus these devices should be derated, in terms of supply voltage, to the lowest level consistent with the required operating speeds.

4.10 Relays and Switches

4.10.1 The functioning of a contact operating device like a switch or relay entails many sources of risk, and incorrect functioning can expose adjacent circuitry to various degrees of hazard. These devices present complex electro-mechanical failure modes; for example, a chopper type relay may occasionally make poor contact with little effect on the overall system operation, while a 'one-shot' armament relay in a missile requires little total usage but demands high reliability when it is used. The conditions that lead to possible failure include ageing of time delay relays and gas generation in hermetically sealed cans.

4.10.2 Most failure modes of relays and switches are dependent upon the cumulative number of operations and, being electro-mechanical devices, relays and switches are subject to both electrical and mechanical failure. Typical causes of failure are predominantly mechanical in nature and include; mis-aligned contacts, open circuit contacts, contaminated or pitted contacts, loss of resilience in contact springs, and open circuit coils.

4.10.3 Contact failure can result from a current surge or high sustained current. Current surges occur in loads which include motors, lamps, heaters, capacitive input filters and other devices with low initial impedance. These currents can cause intense heat with associated contact welding. Transformers can present transients of many times the steady state current. At switch-on a lamp filament can demand current up to 15 times the steady state value and motors up to 10 times.

4.10.4 The following electrical stress ratios for relays and switches are recommended:

$$\text{Stress Ratio} = \frac{\text{Operating Contact Current}}{\text{Rated Contact Current}} = 50\%$$

4.10.5 Special circuit conditions demand a greater degree of derating and the following factors are recommended:

Motor circuit applications	40%
Inductive circuit applications	25%
Lamp filament applications	20%

5. DERATING FOR MECHANICAL EQUIPMENT

5.1 General

5.1.1 Derating information for mechanical equipment is published in various forms and may be provided as individual derating factors for each component type related to one critical stress condition.

5.1.2 Derating is clearly of great importance in mechanical equipment and it is therefore important to consider the impact of environmental and user demands upon a mechanical system when attempting to predict that systems' reliability.

5.1.3 Derating mechanisms for mechanical equipment are often more limited and less clear cut than for electrical and electronic systems. While details of the equipment characteristics and environment are rarely known in full, a few key options exist for the mechanical systems designer wishing to derate a design:

a) <u>Increased Material:</u> Often, the use of a larger item of similar specification will see stresses drop within the item. For example selection of a larger bearing of similar nature (i.e. from the same product range) than is required. However, this approach will often lead to weight increase and over stressing of other parts of the systems as a result. Hence,

b) <u>Improved Material Characteristics:</u> Typical characteristics that will be considered during the design and may be enhanced in order to provide a measure of derating include; corrosion resistance, strength, toughness and hardness. Characteristics that will improve the reliability of an item often compete against one another. For example, to obtain steel that is dimensionally stable at higher temperatures than then hardness will usually have to be sacrificed. Similarly, in order to obtain a highly corrosion resistant item it may be necessary to trade strength or fracture toughness. Strength is often a critical element of all mechanical equipment and use of lighter, stiffer and stronger materials may allow the original design envelope to be maintained while improving the reliability of the design. The problem with this option is that it invariably will lead to higher purchase costs.

c) <u>Redundancy:</u> often used for mechanical fasteners in dynamic load situations where loosening or fatigue cannot be totally eliminated. Use of multiple fasteners rather than a few larger fasteners allows a more precise derating factor to be applied.

d) <u>Manufacturing Process Control:</u> Manufacturing processes have a key role to play in minimising component tolerance variations. Closer fitting parts generally reduce stresses within assemblies as load is more evenly distributed. This applies to the working tolerances between two moving parts (such as a valve stem and its guide) and material consistency considerations (such as material homogeneity in cast components). Improvement in manufacturing process control is one of the major factors behind the increased reliability of the modern motor car. The Japanese car industry has shown that when production volumes are high, then attention to detail design, use of considerable assembly tooling and thorough manufacturing process control techniques can control the above and provide reliable assemblies.

e) Surface Finish: Surface finish can have a large impact upon fatigue strength for mechanical products. Polished surfaces in a steel structure can provide around 30% improvement to the fatigue strength of a component when compared with a plain machined surface. This is due to the reduction in the number and depth of stress raising points on the surface of the item. Therefore, derating can be obtained by using a polish finished item rather than a simple as machined finish.

5.2 Load/Strength Interference

5.2.1 Much work has been undertaken in trying to establish relationships between the load applied to an item, the strength of the item and the resulting reliability of the item. The principle is fairly straightforward, stating that as strength increases above the load then there will be less propensity for the equipment to fail. However, the approach considers an infinite number of items in order to assume a strength distribution. A similar assumption must be made for the loading to generate distributions about the mid point design strength (S) and mean load (L), see Figure 2. As the overlap between the load and the strength distribution reduces it is considered that the reliability will improve as there are less instances of Load>Strength leading to failure. The figure provides examples of alternative strength and process variation properties to demonstrate their impact upon this overlap between the Load and Strength distributions.

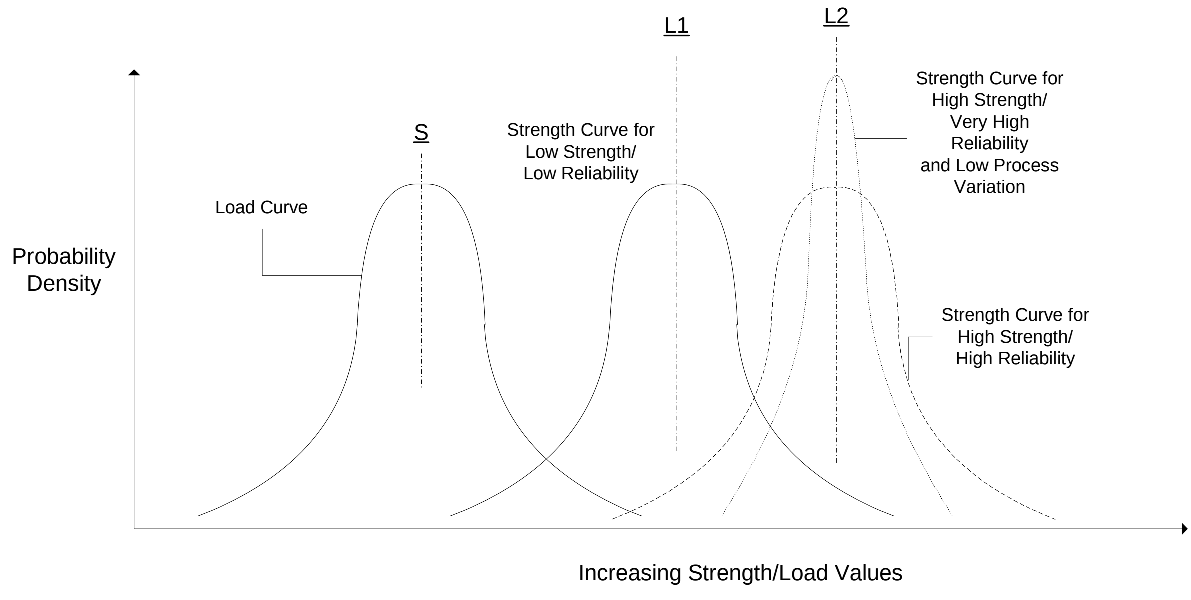

Figure 2 – Ideal Load Vs Strength Curves

5.2.2 Attempts have been made to collect data to support this approach and a number of institutions have claimed success in limited applications, but it is not a widely used process.

5.2.3 Generally the significant stress to be derated is particular to each generic part type, its failure mechanism, operating environment and the maintenance regime. Hence, there are no single recommended derating factors which will ensure a sufficient design margin in most applications for mechanical components. For example, if a relatively simple case of a bearing is considered, there are many options to improve the reliability of the bearing through derating. A wide range of mechanical system attributes can be improved and a far wider range of load factors that must be considered if an analytical or numerical approach is to be taken to the derating process. These include:

a) Dynamic Bearing Loads: Dynamic loads on the bearing will be radial and axial in nature and the general loading envelope will define the choice of bearing. However, the specific variations (loading roughness) in these loads will impact both the life and the reliability of the bearing. Rare peak loads may well cause immediate surface damage to a bearing face with a resultant step increase in the rate of degradation of the bearing.

b) Static Loading: While generally of lower impact than dynamic loads, the static load can lead to localised bearing deformation and damage. Static loading may be due to system weights or misalignment of components. Either can lead to premature bearing failure which is often seen in low production or prototype systems. In a mixed fleet of units this may not come to light as a pattern defect until the system is out of production and possibly out of service. Only gross errors will be identified early in an equipments life. This is an often overlooked factor in military systems which may spend much of their life dormant or in store.

c) Bearing Ambient Temperature: Proximity to a heat source and cooling arrangements will affect the ambient temperature of a bearing. Bearings are capable of working within certain temperature ranges and will add thermal energy to the ambient conditions as they run, see bearing thermal production below. Over temperature in a bearing will result in reduced material stability leading to early life failure (or a reliability failure).

d) Bearing thermal Production: Bearing thermal production is influenced by the inherent friction within the bearing, bearing shaft speed, lubricant characteristics and bearing housing ventilation/heat sink capability. These can all be varied to improve the bearing rating. Bearing surfaces are hardened and the surface hardening may be changed to suit particular (high temperature) circumstances through a process called stabilisation. Such a process can clearly be called upon to prolong the life and improve the reliability of bearing even where not strictly required by the operating constraints. Overheating will often be a secondary failure of the bearing due to a simple reduction of lubrication or it may be that heat from another source (such as in an engine) causes the lubrication parameters to be exceeded and the lubricant to suffer some form of breakdown. Typical bearing failures of this type occur in overhead camshaft engines where the heat is most intense at the top of the engine and the lubrication system is often at its most stretched. Clearly the way to derate these assemblies is to improve the lubrication system capability or make the bearings larger so that they have to handle less intense surface loads.

e) Wear: As the lubricant ages, bearing wear rates will increase due to particulate build up in the lubricant and a reduction in the compressibility characteristics of the lubricant (as it wears out). The primary derating mechanisms available to protect against these faults is to use a high grade lubricant which exceeds the minimum viscosity requirements of the design and may also include additives that may be especially suitable for the application (such as tolerance to moisture or pollutant handling).

5.2.4 Hopefully it can be seen from the simple example above that numerical approaches to the derating (and hence reliability improvement) of mechanical systems is not to be undertaken lightly. It will be a very expensive exercise and should only therefore be undertaken where it can be justified, for example:

a) Loads are fairly limited and simple (such as static structures), or

b) Loss of structural integrity would have catastrophic consequences (aircraft structure, nuclear power plant reactor components).

5.2.5 It is worth noting that derating characteristics which relate a critical environment to the percentage of maximum rating are sometimes available in component manufactures' application data sheets. However, caution must be exercised in the use of mathematical models and graphs as these imply that the environment and relevant equipment attributes are known. In most cases, it is unlikely that these factors will ever be known since it is very difficult, time consuming and expensive, although not impossible, to obtain this information for every component.

5.2.6 The notes contained in Table 2 give guidance on some of the aspects that need to be considered when addressing the issue of mechanical part design rating and derating.

Table 2 – Typical Mechanical Derating Measures

Serial	Item	Typical Failure Mode(s)	Derating Protection Measure Examples
T2.1.1	Seals	Leakage	Material characteristics; Amount of seal compression; Surface finish of seal faces; Seal size; Temperature rating of seal; Fluid contamination level/filtration; Resilience of seal to working fluid; Leakage requirements.
T2.2.1	Springs	Fatigue fracture	Use of similar spring geometry but with superior material properties e.g. adopting higher tensile strength steel. Use of multiple spring sets, or double acting spring sets using two dissimilar springs. Using a physically larger spring.
T2.2.2		Plastic deformation due to load greatly in excess of remaining material strength.	Use of similar spring geometry but with superior material properties e.g. adopting higher tensile strength steel. Use of multiple spring sets, or double acting spring sets using two dissimilar springs. Using a physically larger spring.
T2.3.1	Solenoids	One or more winding shorts; Open coil often caused by overheating.	Design cycle rate of the solenoid; Coil assembly design; Stroke length and clearance tolerances.

Table 2 – Typical Mechanical Derating Measures

Serial	Item	Typical Failure Mode(s)	Derating Protection Measure Examples
T2.4.1	Valves	Seal leakage, worn or damaged valve seat, worn or damaged spool, sticking valve piston in main valve body, broken spring or damaged spring ends, inoperative solenoid assembly, external leakage or cracked connector/housing	Material hardness; Surface finish; Physical size; Operating fluid cleanliness/filtration; Resilience of valve material to working fluid; Leakage requirement; Clearance tolerances.
T2.5.1	Bearings	Overloading; Brinelling.	Overloading of all mechanical devices is a common cause of failure and often cannot be discerned after the event as the overload condition may cause a small area of damage which with time causes the bearing to fail. Therefore by the time of failure the initiating cause may well be forgotten. The best form of protection for such failures is to ensure that the stated speed, load and lubrication requirements of the bearing design are understood and derated by some degree
T2.5.2		Misalignment in the concentricity of the bores of a set of bearings; Distortion of the bearing housing on assembly; Distortion of the bearing housing or the alignment of a set of bearings as operating temperatures rise.	Process Control; Material characteristics; Bearing housing ventilation/heat sink capability; Bearing type, ball bearings are generally used where there is likely to be excessive misalignment or shaft deflection.

Table 2 – Typical Mechanical Derating Measures			
Serial	**Item**	**Typical Failure Mode(s)**	**Derating Protection Measure Examples**
T2.5.3		Overheating	Surface hardening; Inherent friction within the bearing due to lubrication; Bearing shaft speed; Lubricant characteristics/additives; Bearing housing ventilation/heat sink capability.
T2.5.4		Wear due to lubricant or sealing failure. Wear rates will increase due to particulate build up in the lubricant.	The primary derating mechanisms available to protect against these faults is to use a high grade lubricant which exceeds the minimum viscosity requirements of the design and may also include additives that may be especially suitable for the application (such as tolerance to moisture or pollutant handling). In plain bearings the lubricant may also be changed or cleaned periodically to maintain its performance. For sealed bearings the failure of seals may be protected by measures as described above in Serial T2.1.1.
T2.6.1	Gears and Splines	Gear tooth corrosion, erosion and subsequent break up.	Material properties, especially hardness; Surface finish; Physical size; Operating fluid cleanliness/filtration; Mounting accuracy and housing stability under load and temperature.

Table 2 – Typical Mechanical Derating Measures			
Serial	**Item**	**Typical Failure Mode(s)**	**Derating Protection Measure Examples**
T2.7.1	Threaded fasteners	Shearing due to: Hydrogen embrittlement; Stress corrosion cracking at thread root; Fatigue due to cyclic loading induced due to direct load or thermal expansion cycles; Seizure during maintenance.	Material properties, especially toughness and corrosion resistance. These may be due to the production process. Rolled threads are tougher than machined or ground threads and threads rolled after heat treatment show better fatigue performance than threads rolled before heat treatment. Surface finish; Physical size; Redundancy.
T2.7.2		Loosening due to: Fatigue due to cyclic loading induced due to direct load or thermal expansion cycles; Reduction in locking face torque due to lubricant ingress; Joint relaxation,	Mounting accuracy and housing stability under load and temperature; Lubricant type and properties; The effective coefficient of friction can alter the installation torque requirements by as much as 50% to 100%; Surface finish; Physical size and hence ultimate locking load of the fastener; Redundancy.

Table 2 – Typical Mechanical Derating Measures			
Serial	**Item**	**Typical Failure Mode(s)**	**Derating Protection Measure Examples**
T2.8.1	Friction Drive/Brake devices	Loss of drive/brake effort due to burning or break up of lining material due to thermal cycling or intense thermal build up. This can lead to deformation of the non wearing parts and subsequent total failure of the device.	Relative positional accuracy and housing stability under load and temperature to ensure faces remain true. Material properties, such as thermal conductivity thermal stability, tensile strength and compressive strength. Physical size which will assist in thermal shedding ability. Device ventilation/heat sink capability, which can typically be enhanced by using hollow sections and forced air cooling.

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