

Plant and Equipment Wellness Tutorial: Component Lifetime Health Strategy Based on Physics-of-Failure Science

“A coherent, complete and standardised business-wide process to recover the utmost value and productivity from existing facilities, equipment and infrastructure.”

Let a Plant Wellness Way EAM System-of-Reliability End Your Business Risks Forever

Plant and Equipment Wellness (PEW) is a Physics of Failure based methodology for equipment failure prevention and defect elimination that results in the fewest activities, least resources and lowest expenditure to produce outstanding operational equipment reliability. PEW identifies the necessary business-wide processes and departmental actions an organisation needs to apply to get high plant and equipment availability. With high uptime comes more productivity, higher operating profits, and less capital expenditure.

As much as possible PEW uses simple techniques that can be done by shopfloor people. Most companies do not have large staffs of university trained maintenance and reliability professionals. They have knowledgeable and experienced maintenance practitioners that know their plant and equipment. PEW does not require specialist RAMS software that none but mathematicians can understand, that very few companies can afford to buy or contract, and requires assumptions about the future that are hopeful at best.

PEW needs only the basics of engineering and financial knowledge to use and be able to deliver a brilliant business strategy for lasting operating equipment reliability. Where operations have access to reliability analysis and maintenance optimisation tools and software they are used to understand what options will be most effective. But you do not need such tools and software to use the PEW methodology and still be sure that you have developed a sound and powerful maintenance and reliability improvement strategy.

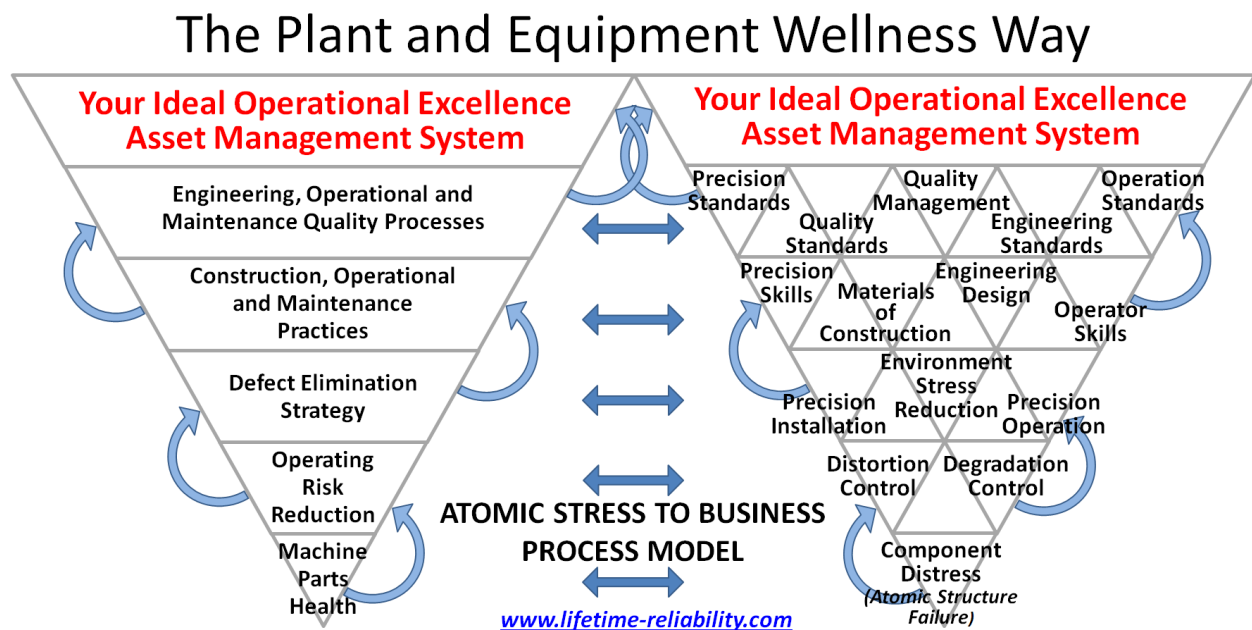


Figure 1 The ‘Stress to Process’ Plant and Equipment Wellness Model

The PEW approach summarised in Figure 1 provides not only a list of what tasks must be done in your maintenance and reliability strategy, it also specifies how well each must be done so you ensure outstanding performance. You will develop the right strategy and design the necessary business-wide systems to support achievement of that strategy.

The PEW methodology identifies the right maintenance and asset management strategy for outstanding plant and equipment reliability. Unlike RCM, Reliability Centred Maintenance (RCM) where the answers to strategy selection questions offer no certainty of their effectiveness, with PEW you will know that you have the right activities and practices in-place to get both amazing equipment reliability and least operating costs. Furthermore, the PEW activities that arise from a Physic of Failure analysis are used repeatedly whenever an identical situation arises in any machine.

Because all our machines are made from about 100 different types of elements¹ (though of various sizes and materials) you will quickly develop a library of catalogued analyses that you replicate for all similar equipment. For example, once you have analysed one gearbox you have virtually completed the analysis for all other similar gearboxes.

To get the most from a PEW analysis quickly, group all similar equipment types together, e.g. gearboxes, control valves, induction electric motors, Programmable Logic Controllers (PLCs), electrical transformer, etc, and do one PEW analysis for each type. Then every time this equipment type occurs use the original analysis and only look for exceptions particular to the equipment under review. Similarly, when a part done in a previous PEW analysis reappears in another machine, e.g. bearings, lubricant, shafts, fasteners, etc, use the results of the previous PEW analysis and confirm there are no exceptions that need to be separately addressed.

Do not be fearful if you have thousands of physical assets; the PEW analysis results will repeat for common types of equipment, and they will also repeat for parts in identical situations even when the equipment types are different. Provided you develop a logical cataloguing convention identifying both equipment type and part type you will quickly locate a suitable previous analysis if one exists and can then reuse it and only need to check for exceptions.

Because there are replicated elements in your machinery a repeating set of failure causes reoccur when the three Physics of Failure Factors questions are answered. Collect these repeating causes into 'guidewords' for use in all future PEW analyses to help identify causes of failure. This allows a PEW analysis to be prepared ahead of time by one person and later reviewed by knowledgeable individuals or by a team convened to do the review. The PEW approach eventually reduces the time and manpower needed to do a comprehensive and accurate analysis of a complete site.

The Steps in a Plant and Equipment Wellness Analysis

There are eight questions to be answered during the analysis. These are listed below.

Economic Factors

1. Are the business-wide consequences of an equipment failure acceptable?
2. Where failure is acceptable how frequently can it occur before it becomes unacceptable?

Physics of Failure Factors of Parts Failure

3. How can the part's atomic structure be overstressed?
4. How can the part's atomic structure be fatigued?
5. How can the part's atomic structure be degraded?

¹ Hattangadi A. A., *Plant and Machinery Failure Prevention*, Page 4, McGraw-Hill, 2005

Organisational Factors in Parts Failure

6. What human factors allow the part to fail?
7. What business processes allow the part to fail?
8. What design issues allow the part to fail?

The answers to the economic factors determine if an analysis is required for the equipment. Where the failure of an item of equipment is unimportant the default decision is to run-to-failure and rectify the situation in a timely manner suited to the operational needs.

Step 1: Collect Together All Technical Information

Because machines fail only after their critical parts fail PEW requires us to identify those parts in a machine that will stop the machine operating at minimum duty should they fail.

Up-to-date Process Drawings, Equipment Drawings, General Assembly (GA) Drawings, Manufacturer Manuals, Parts Assembly Drawings and Bills of Material are collected together so that they can be reviewed to identify the critical equipment in a production process. Later the critical parts within the equipment will be identified so the appropriate activities can be done to keep each critical part at exceptional reliability. An example of a GA for gear-motors is Figure 2.

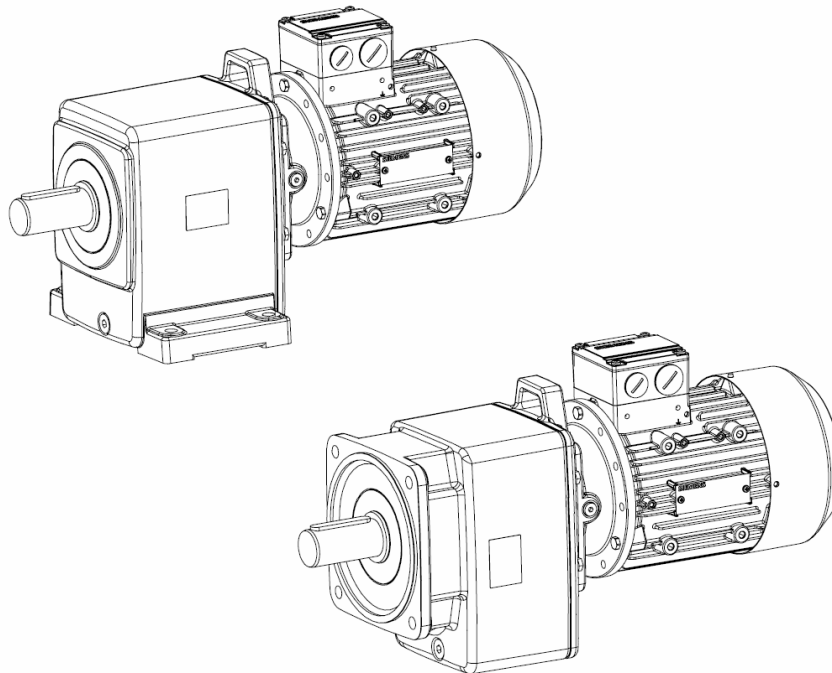


Figure 2 Industrial Gear-Motor Units

An example of a parts Assembly Drawing is Figure 3 in which is shown a drive gearbox assembly ‘exploded’ into its individual parts so they can be identified and shown how they each fit together to make the final operating unit.

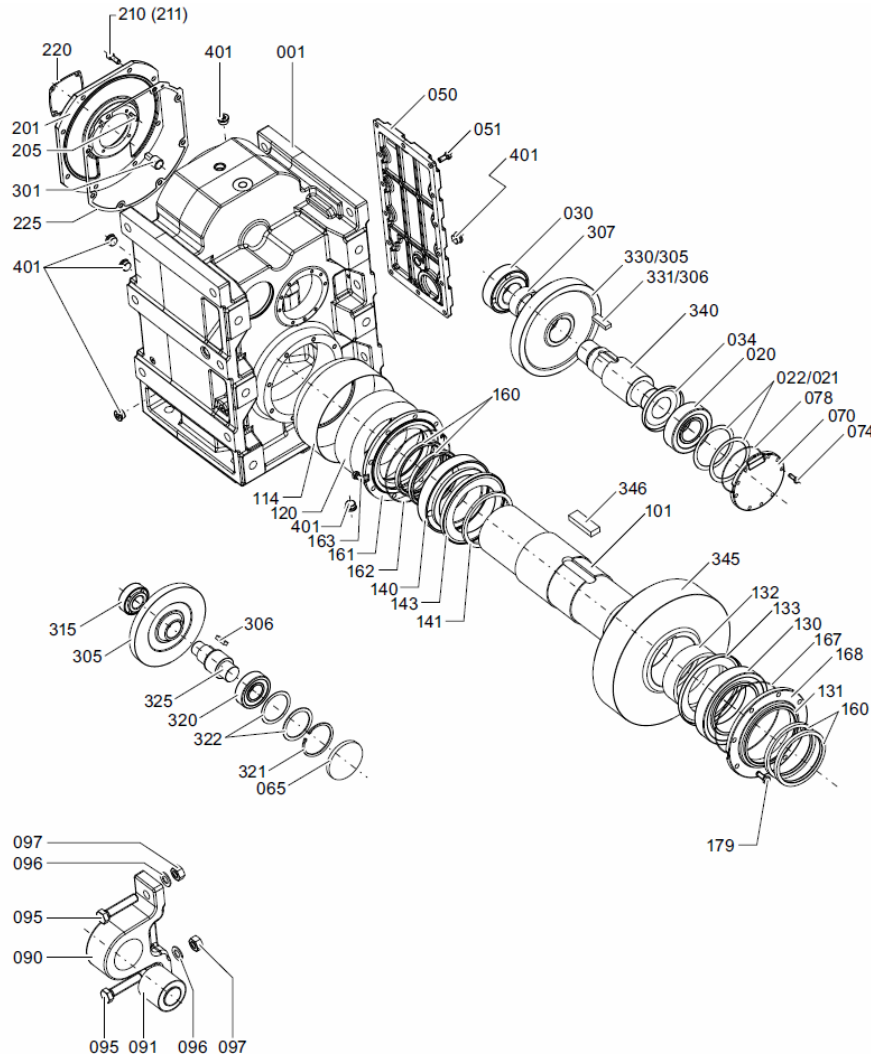


Figure 3 Exploded Assembly Drawing of a Gear-Motor Drive (not a Figure 1 unit)

In the same manual as the exploded parts drawing will be the parts list that describes each of the part numbers shown on the parts assembly drawing. Figure 4 shows the parts list for the gearbox of Figure 3. Throughout the analysis the same number and description of each part is used in combination with the manufacturers name and model number.

Where a manufacturer uses a specific part numbering sequence it is adopted during the analysis to retain commonality during the analysis and for later easy reference. Where the manufacturer does not have a part numbering classification you need to create an individual part numbering and naming convention. A suitable part numbering convention is of the form:

Manufacturer code – equip type – model number – assembly no. – part no. – part description

If necessary ‘dummy’ numbers and codes can be used to create an individual number for all parts.

001	Gearbox housing	162	O-ring
020	Bearing	163	Screw
021	Supporting disk / shim	167	O-ring
022	Supporting disk / shim	168	Bearing cover
025	Locking ring	179	Screw
030	Bearing	201	Adapter plate
034	NILOS ring	205	Screw
040	Output flange	210	Screw
045	Screw	211	Screw lock
050	Housing cover	220	Seal
051	Screw	225	Seal
055	Seal	301	Pinion
065	Sealing cap	305	Helical gear wheel
070	Sealing cap	306	Parallel key
074	Screw	307	Spacer / bush
078	O-ring	310	Locking ring
090	Torque arm	311	Supporting disk / shim
091	Rubber bush	315	Bearing
095	Screw	320	Bearing
096	Locking ring	321	Locking ring
097	Nut	322	Supporting disk / shim
101	Input shaft	325	Pinion shaft
109	Locking ring	330	Helical gear wheel
110	Locking ring	331	Parallel key
114	Protection cover (optional)	340	Pinion shaft
120	Shrink disk	345	Helical gear wheel
128	Supporting disk / shim	346	Parallel key
129	Supporting disk / shim	401	Screw plug
130	Bearing	420	Vent filter
131	Supporting disk / shim		
132	Spacer / bush		
133	NILOS ring		
135	Locking ring		
140	Bearing		
141	Spacer / bush		
143	NILOS ring		
144	Supporting disk / shim		
146	Locking ring		
160	Shaft sealing ring		
161	Bearing cover		

Figure 4 Parts List with Description of Each Part Number

Step 2: Business Impact Review

Equipment by equipment is reviewed to determine what the impact of failure is on the operation. We ask the following Economic Factors Questions and the answers guide our decision making.

1. Are the business-wide consequences of an equipment failure acceptable?
2. Where failure is acceptable how frequently can it occur before it becomes unacceptable?

Equipment such as the gear-motors in Figure 2 drive production machinery and when they fail the production plant stops. People in the Operations Group will know if the failure of an equipment item will cause a production stoppage that has a business impact or the failure is of no consequence.

If frequent failure of the equipment is acceptable it is allowed to fail and the analysis goes no further for that item of equipment. The default maintenance and operating strategy for such equipment is run-to-failure and no maintenance activity is performed on it and no spare parts are carried in store for it. At the time the equipment breaks the decision is made to rectify it or else to address the failure in an appropriate way. Corrective actions are instigated after failure and the accompanying costs and

time delays are accepted without concern since a failure of the equipment does not matter to the business.

Where a failure is unacceptable, or where a failure that happens too frequently is unacceptable, the business-wide economic impact of the equipment's failure needs to be determined to an acceptable degree of accuracy (typically $\pm 20\%$ of total business costs and losses). This means estimating the actual moneys lost business-wide when the equipment fails its minimum service duty.

The business-wide costs of failure are tallied using the Defect and Failure True Costs (DAFT Costs) spreadsheets. All direct costs and indirect costs and losses incurred throughout the company because of the failure are recorded and totalled. Gathering the DAFT Costs requires access to operational, maintenance and accounting data to trace the knock-on impacts of failures. The total business-wide costs and losses are needed accurately enough to be believed to managers and defensible when challenged by others.

The business impact is marked on a calibrated business risk matrix like that in Figure 5. This makes the business risk quantified and visible to everyone. Where the risk is outside the company's risk boundary actions must be taken to reduce the risk to what the operation will accept.

The calibrated risk matrix represents the annual business-wide losses from an unwanted event. The value is arrived at from the following equation.

$$\text{Risk (\$/yr)} = \text{Likelihood (events/yr)} \times \text{Consequence (\$/event)}$$

The Consequences of a failure event are its business-wide DAFT Costs. The Likelihood is the historical annual frequency that the event happens in the business or in other comparable, similarly operated businesses.

The matrix is calibrated so the Low Risk level represents the business risk boundary. Below the boundary risks are acceptable. Above the boundary risks are acted on with strategies and actions that reduce the risk to below the Low Risk boundary value. In Figure 5 the risk boundary is set at an annual cost of \$10,000 per event. The business will accept one failure per year if it costs less than \$10,000, but will act to reduce those situations where a failure event will cost more than \$10,000 annually. Note that this also means the operation will accept a \$100,000 loss event every ten years and will do no more to prevent it beyond ensuring the event will happen no more often than once every ten years.

By using the risk matrix we can quantify the scale of a loss event and we can immediately see the quantum of savings made if we reduce the risk to acceptable levels. The savings made from reducing the risk justify an amount of expenditure to reduce the risk. For example, if an event occurs every two years that costs the business represented by Figure 5 \$100,000 when it happens, the risk is then High at \$50,000/year. If the likelihood of the event could be reduced to once every ten years with mitigating actions that brought it down to the \$10,000/yr risk boundary, the business would then gain \$40,000 in additional operational profit each year.

Provided the mitigations were certain to be successful the business could justify spending up to \$39,999 per year to prevent the \$40,000 loss and so make \$1 more profit annually than it now does. If the risk could be surely reduced to a Low level for a cost of \$10,000/yr then the operating profit would increase \$30,000 annually for an expenditure of \$10,000 yearly; a lasting 300% annual return on investment.

Likelihood of Equipment Failure Event per Year				DAFT Cost per Event	\$30	\$100	\$300	\$1,000	\$3,000	\$10,000	\$30,000	\$100,000	\$300,000	\$1,000,000	\$3,000,000	\$10,000,000	\$30,000,000	\$100,000,000	\$300,000,000	\$1,000,000,000
Event Count per Year	Time Scale	Descriptor Scale	Historic Description		1.5	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7	7.5	8	8.5	9
100	Twice per week			7	8.5	9	9.5	10	10.5	11	11.5	12	12.5	13	13.5	14	14.5	15	15.5	16
30	Once per fortnight			6.5	8	8.5	9	9.5	10	10.5	11	11.5	12	12.5	13	13.5	14	14.5	15	15.5
10	Once per month	Certain		6	7.5	8	8.5	9	9.5	10	10.5	11	11.5	12	12.5	13	13.5	14	14.5	15
3	Once per quarter			5.5				8.5	9	9.5	10	10.5	11	11.5	12	12.5	13	13.5	14	14.5
1	Once per year	Almost Certain	Event will occur on an annual basis	5					8.5	9	9.5	10	10.5	11	11.5	12	12.5	13	13.5	14
0.3	Once every 3 years	Likely	Even has occurred several times or more in a lifetime career	4.5					8.5	9	9.5	10	10.5	11	11.5	12	12.5	13	13.5	14
0.1	Once per 10 years	Possible	Event might occur once in a lifetime career	4						8.5	9	9.5	10	10.5	11	11.5	12	12.5	13	14
0.03	Once per 30 years	Unlikely	Event does occur somewhere from time to time	3.5							8.5	9	9.5	10	10.5	11	11.5	12	12.5	13
0.01	Once per 100 years	Rare	Heard of something like it occurring elsewhere	3								8.5	9	9.5	10	10.5	11	11.5	12	13
0.003	Once every 300 years			2.5									8.5	9	9.5	10	10.5	11	11.5	12
0.001	Once every 1,000 years	Very Rare	Never heard of this happening	2										8.5	9	9.5	10	10.5	11	12
0.0003	Once every 3,000 years			1.5											8.5	9	9.5	10	10.5	11
0.0001	Once every 10,000 years	Almost Incredible	Theoretically possible but not expected to occur	1												8.5	9	9.5	10	11

Note:

- 1) Risk Boundary is set at 'LOW' Level
- 2) Based on HB436:2004-Risk Management
- 3) Identify 'Black Swan' events as B-S (A 'Black Swan' event is one that people say 'will not happen' because it has not yet happened)
- 4) DAFT Cost (Defect and Failure True Cost) is the total business-wide cost from the event

Risk = \$100,000/yr event

Figure 5 Business Risk Matrix Calibrated to an Annual Risk of \$10,000 per Event

When we find the business impact of an equipment failure is greater than the organisation will tolerate we put into place those appropriate actions that reduce risk to below the acceptable boundary and will hold it there forever more.

The mitigation methods and actions we chose must be effective in reducing the risk by either lowering the consequential business-wide impact of the event and/or lowering likelihood of the event occurring. If a mitigation action does not deliver one or the other (reduced consequence or frequency) it is a pointless waste of resources and it is discarded and a better action is chosen.

We must be convinced that what is done to reduce risk will work and it will remain at the Low risk level. We measure the effectiveness of our chosen mitigations on a risk matrix to ensure they will indeed bring the desired results. Figure 6 shows how the effectiveness of mitigations are checked and proven to deliver economic value. In the example the consequence of the failure event is unchanged but the likelihood has substantially reduced because of new mitigations used.

Where a number of mitigations are required to operate collectively in order to achieve the required risk reduction it may be necessary to accept a less than brilliant individual activity because it is an integral part of the total risk reduction solution.

Risk Reduction Decision Rules

The mitigations we use will have to meet the criteria of reducing the frequency and/or reducing the consequence. There are two rules that are followed, one for each of the two factors that determine the size of business risk.

A mitigation that reduces likelihood is acceptable if and only if it significantly reduces the stress in a part. It is achieved by ensuring the incidents that generate forces and loads which can create excessive atomic stress do not occur during the operating life of the equipment.

A mitigation that reduces consequence is acceptable if and only if it significantly reduces the consequential cost should the failure event initiate. It is achieved by doing activities upon fail initiation that minimise the business-wide costs spent and moneys lost because of the event.

Likelihood of Equipment Failure Event per Year				DAFT Cost per Event	\$30	\$100	\$300	\$1,000	\$3,000	\$10,000	\$30,000	\$100,000	\$300,000	\$1,000,000	\$3,000,000	\$10,000,000	\$30,000,000	\$100,000,000	\$300,000,000	\$1,000,000,000
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100	Twice per week			7	8.5	9	9.5	10	10.5	11	11.5	12	12.5	13	13.5	14	14.5	15	15.5	16
30	Once per fortnight			6.5	8	8.5	9	9.5	10	10.5	11	11.5	12	12.5	13	13.5	14	14.5	15	15.5
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0.0001	Once every 10,000 years	Almost Incredible	Theoretically possible but not expected to occur	1													8.5	9	9.5	10

Risk = \$10,000/yr event

Note: Risk Level
 Red = Extreme
 Amber = High
 Yellow = Medium
 Green = Low
 Blue = Accepted

1) Risk Boundary is set at 'LOW' Level
 2) Based on H436:2004-Risk Management
 3) Identify 'Black Swan' events as B-S (A 'Black Swan' event is one that people say 'will not happen' because it has not yet happened)
 4) DAFT Cost (Defect and Failure True Cost) is the total business-wide cost from the event

Figure 6 Business Risk Matrix showing Effectiveness of Risk Mitigations

Now that we have found the money to pay for risk reduction practices we must identify those situations that produce the operating risks which eventual become the failures that waste our operating profit and stop production.

Step 3: Decide to Analyse or Not to Analyse

If the business-wide cost of a failure is below the risk boundary for the business do not spend time conducting an analysis. You will get greater value from your time by doing analysis of high risk situations. For example, if a gear-motor unit like those of Figure 2 failed it would cost US\$1,500 to US\$2,500 to buy a new one depending on the size. It would take four hours to change the unit out at a direct maintenance cost of about US\$1,000. Provided a new unit could be sourced within an hour the business-wide impact of costs and losses in a manufacturing operation could reach US\$25,000. If failure happened no sooner than every 10 years the annualised risk is US\$2,500. This risk is well below the US\$10,000/year risk boundary of our imaginary manufacturer and thus our maintenance strategy defaults to accepting that failure. With ten years between failure you would not maintain the gearbox but replace it when it failed.

However, if the same gearbox failed every two years and each failure cost US\$25,000 you would have to address the reasons for failure because the annualised cost is US\$12,500, which is now above our self-imposed US\$10,000/year risk boundary. In this case you cannot accept a run-to-fail strategy and will need to develop mitigation to reduce the frequency of failure.

The trap you fall into with the above approach is that you end up only maintaining equipment that is high risk and leaving the equipment that is acceptable risk until it fails. You have designed into your

operation many breakdowns of unimportant machines and equipment and you will waste your time doing unimportant activities and spend your maintenance budget on unimportant plant.

You remove that trap by being proactive and replacing unimportant equipment before they are likely to fail. In the case of the gearbox the strategy becomes to replace it brand-new every ten years in a planned shutdown and renew it so that the equipment starts fresh into another ten year run.

Step 4: Identify Critical Parts in Equipment

Once we have decided that the risk of an equipment failure is too high for the operation to carry we apply Physics of Failure analysis to find what can cause the equipment's critical parts to fail and develop plans and actions to prevent their failure. These plans and actions can apply to any and all issues related to the organisation's design engineering, operational and maintenance practices. We care only that the real operating risk is below the risk boundary and any mix of economically viable solutions that delivers that outcome are acceptable. We use the calibrated risk matrix to identify the economic viability of a proposal—if a strategy or action reduces risk it is potentially viable.

An example of analysing if a part is critical follows. Figure 7 is the drawing of an electric motor drive end bearing and housing.

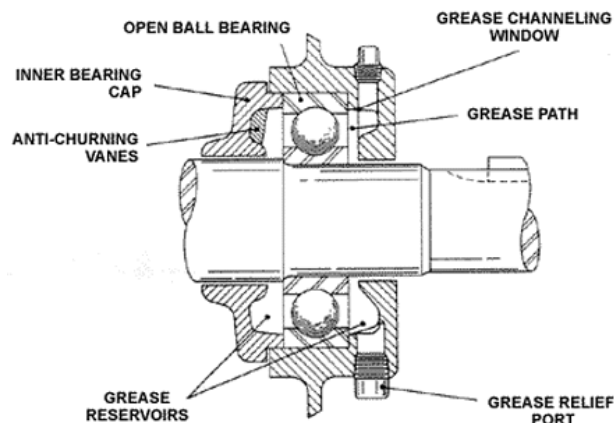


Figure 7 AC Electric Motor Bearing Arrangement

The critical components are identified by using a 'design logic' process flow map (also called a reliability block diagram) of the assembly under consideration. In Figure 8 a portion of the bearing assembly mounted on the shaft of Figure 7 is drawn mimicking its logical sequence of operation.

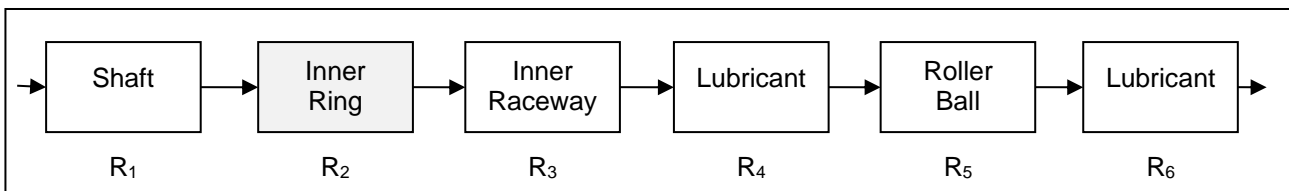


Figure 8 Process Flow Map for Roller Bearing on Shaft

The flow chart immediately highlights that each part is critical since each part is in a series arrangement chain-of-parts. The loss of a part, like the failed raceway of Figure 9, causes the roller bearing to fail and the motor to stop. You quickly see from the process map what happens to the machine once a part's reliability (R) falls to zero and it no longer can do its function in the chain of parts. When the part fails the machine fails; the equipment stops and so does production.

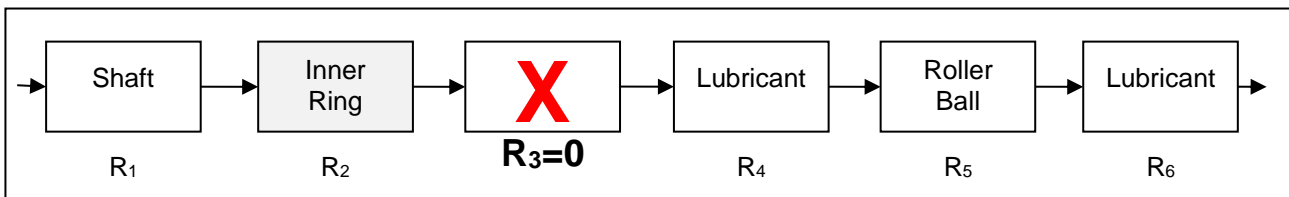


Figure 9 Process Flow Map with Roller Bearing Raceway Failure

It is often not necessary to draw process maps for machinery since the assembly drawings can be viewed directly and the critical parts identified by sight. The critical parts in the exploded gearbox drawing of Figure 2 are easily identifiable to a person experienced in the construction of such equipment. When there is uncertainty about a part's critical nature a design logic process flow map drawn for the part and its neighbours will clarify the situation.

Step 5: Physics of Failure Factors Analysis of Critical Parts

The next step is to identify the physical reasons that a critical equipment part can fail and for each cause determine what actions and practices will prevent the occurrence. For each critical part ask the three Physics of Failure (PoF) questions to find the incidents that destroy the atomic structure.

1. How can the part's atomic structure be overstressed?
2. How can the part's atomic structure be fatigued?
3. How can the part's atomic structure be degraded?

We are not after the root cause of a failure. One failure can be the result of dozens of root causes, many of which can never be identified. **We do not focus on rectifying a problem, instead we focus on not having the problem in the first place.** Each question takes us back to the basic engineering and physics that provides the integrity of a part and requires us to identify how the integrity is lost. For each way that a part loses integrity we must find suitable and viable solutions.

The questions are answered in the PEW Analysis Spreadsheet along with the actions to be taken to prevent the failure. This approach lets us design operational and maintenance business processes and activities that deliver incredible reliability from our machines and equipment because we prevent all root causes from starting and developing into a failure.

Figure 10 is an example of the PoF Analysis spreadsheet for the pinion in the gear-motor.

PEW_Analysis_Spreadsheets.xls [Compatibility Mode] - Microsoft Excel

File

Home

Insert

Page Layout

Formulas

Data

Review

View

Paste

Cut

Copy

Format Painter

Clipboard

Font

Alignment

Number

Conditional Formatting

Format as Table

Styles

Insert

Delete

Format

Cells

AutoSum

Fill


Clear

Sort & Filter

Find & Select

Editing

T39

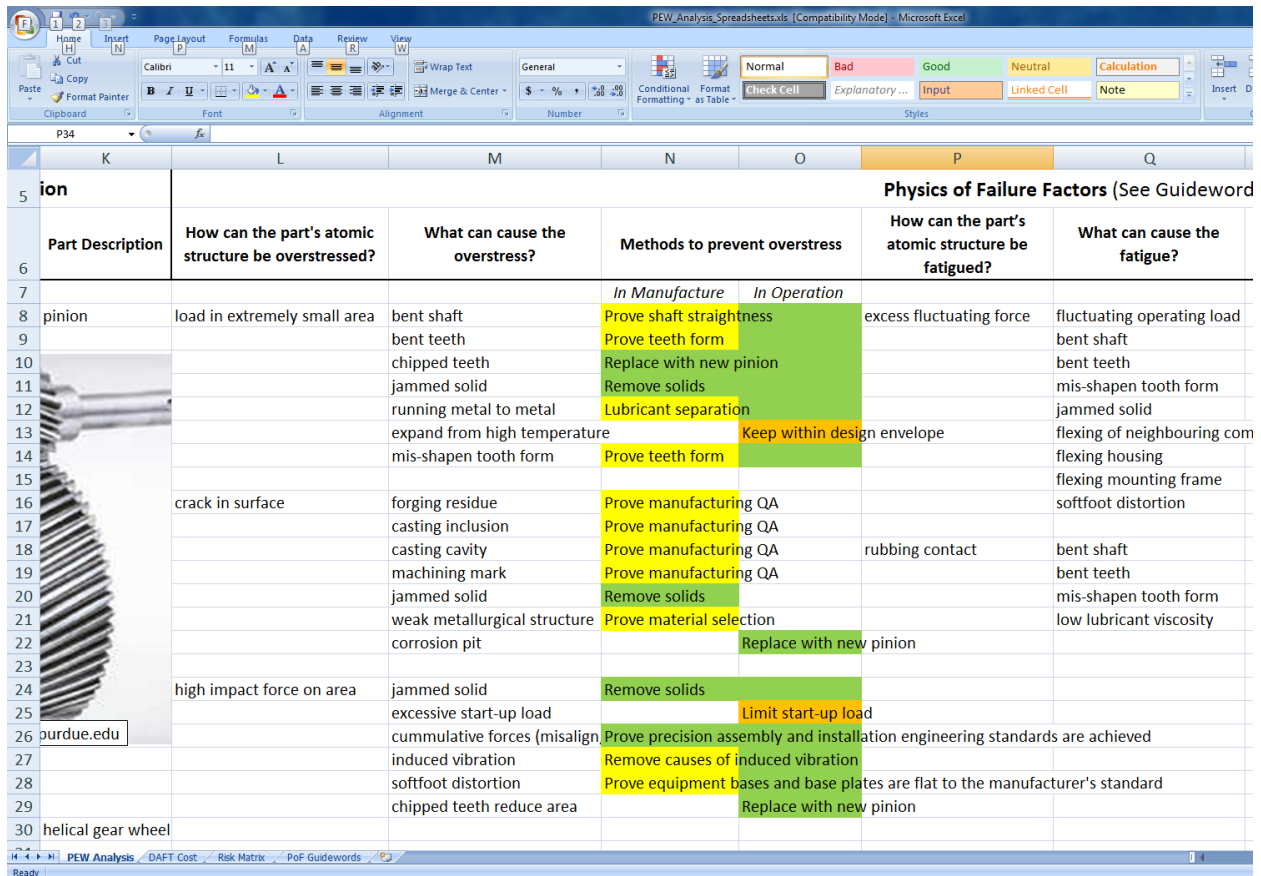
	I	J	K	L	M	N	O	P	Q	R	S	T
1												
2												
3												
4												
5	Part Identification			Physics of Failure Factors (See Guidewords List)								
6	Equipment Assy Description	Part Number	Part Description	How can the part's atomic structure be overstressed?	What can cause the overstress?	Methods to prevent overstress	How can the part's atomic structure be fatigued?	What can cause the fatigue?	Methods to prevent fatigue	How can the part's atomic structure be degraded?	What can cause the degradation?	Methods to prevent degradation
7												
8	Gearbox	301	pinion	load in extremely small area	bent shaft bent teeth chipped teeth jammed solid running metal to metal expand from high temperature mis-shapen tooth form	Prove shaft straightness Prove teeth form	excess fluctuating force	fluctuating operating load bent shaft bent teeth mis-shapen tooth form jammed solid flexing of neighbouring components flexing housing flexing mounting frame softfoot distortion		attack metallurgical elements	corrosion water in lubricant corrosive chemical	
9												
10												
11												
12												
13												
14												
15												
16												
17												
18					crack in surface	forging residue casting inclusion casting cavity machining mark jammed solid weak metallurgical structure		rubbing contact	bent shaft bent teeth mis-shapen tooth form low lubricant viscosity			
19												
20												
21												
22												
23												
24				high impact force on area	jammed solid excessive start-up load cumulative forces (misalign, out-of-balance, softfoot) induced vibration softfoot distortion chipped teeth reduce area							
25												
26												
27												
28												
29												
30		305	helical gear wheel									
31												
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36												
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38												

PEW AnalysisDAFT CostRisk MatrixPoF Guidewords

Figure 10 Partial Physics of Failure Factors Analysis for Gearbox Drive Pinion

Step 6: Selecting High Reliability Strategy

Each of the issues in the PoF factors list need to be addressed proactively to prevent failure starting. This requires us to select actions that prevent the cause from occurring in the first place. One by one life cycle engineering, maintenance and operational decisions are made so each cause is prevented with the appropriate action or combination of actions. Figure 11 shows the actions selected to protect the pinion from life cycle opportunities to fail by becoming overstressed.



Physics of Failure Factors (See Guideword)					
Part Description	How can the part's atomic structure be overstressed?	What can cause the overstress?	Methods to prevent overstress		How can the part's atomic structure be fatigued?
			In Manufacture	In Operation	
pinion	load in extremely small area	bent shaft	Prove shaft straightness		excess fluctuating force
		bent teeth	Prove teeth form		fluctuating operating load
		chipped teeth	Replace with new pinion		bent shaft
		jammed solid	Remove solids		bent teeth
		running metal to metal	Lubricant separation		mis-shapen tooth form
		expand from high temperature		Keep within design envelope	jammed solid
		mis-shapen tooth form	Prove teeth form		flexing of neighbouring com
	crack in surface	forging residue	Prove manufacturing QA		flexing housing
		casting inclusion	Prove manufacturing QA		flexing mounting frame
		casting cavity	Prove manufacturing QA		softfoot distortion
		machining mark	Prove manufacturing QA		
		jammed solid	Remove solids		bent shaft
		weak metallurgical structure	Prove material selection		bent teeth
		corrosion pit		Replace with new pinion	mis-shapen tooth form
	high impact force on area	jammed solid	Remove solids		low lubricant viscosity
		excessive start-up load		Limit start-up load	
		cumulative forces (misalign	Prove precision assembly and installation		engineering standards are achieved
		induced vibration	Remove causes of induced vibration		
		softfoot distortion	Prove equipment bases and base plates are flat to the manufacturer's standard		
		chipped teeth reduce area		Replace with new pinion	
helical gear wheel					

Figure 11 Identifying Necessary Actions for High Component Reliability

The analysis only needs to be done by one person who is knowledgeable and experienced in the equipment. Once they complete their analysis it is reviewed by a separate person(s), also competent in the equipment, for additional factors and actions that should be included in the list.

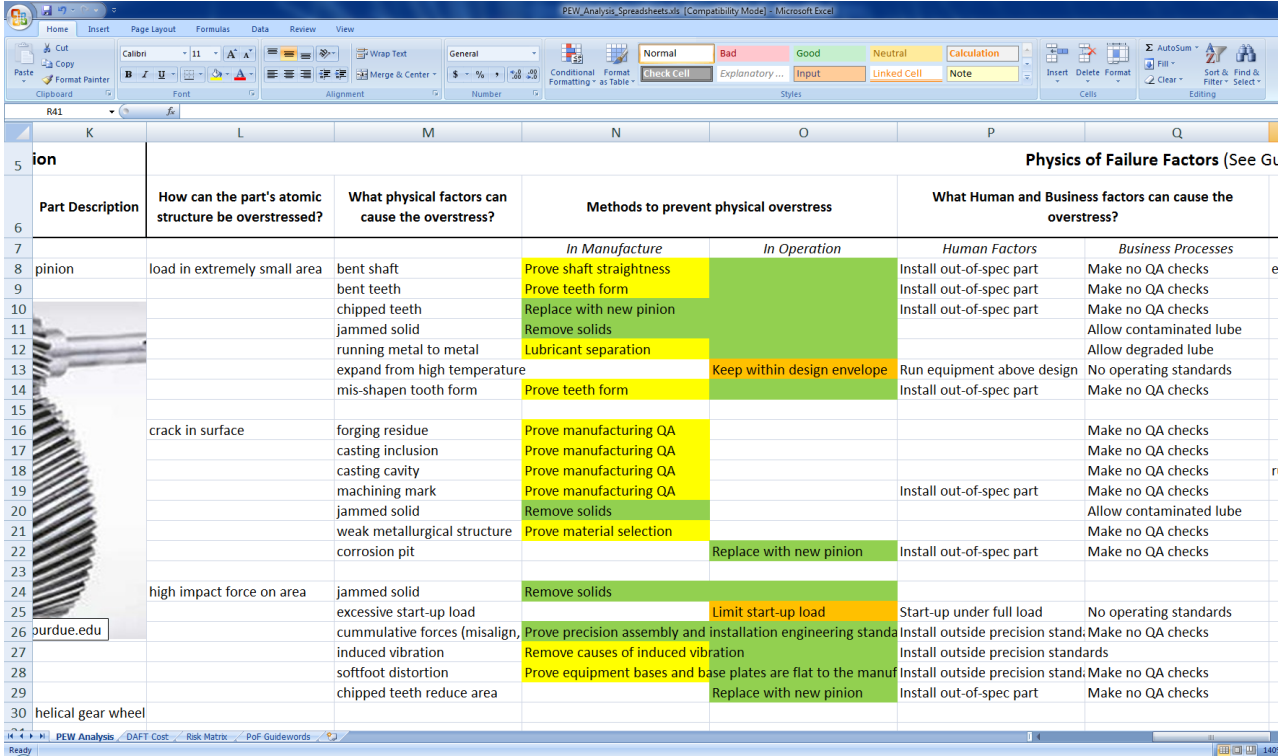
Step 7: Organisational Factors Analysis of Critical Parts Failure

It is well researched that around 80 percent of equipment failures can be traced back to human error and unintended business process and procedural 'traps' that cause calamity². You must confront the reality of the three Organisational Factors questions used to expose introduced failure:

1. What human factors allow the part to fail?
2. What business processes allow the part to fail?
3. What design issues allow the part to fail?

² Sondalini, M., 'Plant and Equipment Wellness – a process for exceptional equipment reliability and maximum life cycle profits', Page 86, Engineers Australia Books, 2009

Notice that the human and business factors in Figure 11 recur again and again. No matter how many parts you put through this analysis you will soon collect a short list of the human and business drivers of failure in your operation and see that they are always the same ones repeating endlessly. You have identified the systemic causes creating your equipment problems.



Part Description	How can the part's atomic structure be overstressed?	What physical factors can cause the overstress?	Methods to prevent physical overstress		What Human and Business factors can cause the overstress?	
			In Manufacture	In Operation	Human Factors	Business Processes
pinion	load in extremely small area	bent shaft	Prove shaft straightness		Install out-of-spec part	Make no QA checks
		bent teeth	Prove teeth form		Install out-of-spec part	Make no QA checks
		chipped teeth	Replace with new pinion		Install out-of-spec part	Make no QA checks
		jammed solid	Remove solids			Allow contaminated lube
		running metal to metal	Lubricant separation			Allow degraded lube
		expand from high temperature		Keep within design envelope	Run equipment above design	No operating standards
		mis-shapen tooth form	Prove teeth form		Install out-of-spec part	Make no QA checks
	crack in surface	forging residue	Prove manufacturing QA			Make no QA checks
		casting inclusion	Prove manufacturing QA			Make no QA checks
		casting cavity	Prove manufacturing QA			Make no QA checks
		machining mark	Prove manufacturing QA		Install out-of-spec part	Make no QA checks
		jammed solid	Remove solids			Allow contaminated lube
		weak metallurgical structure	Prove material selection			Make no QA checks
		corrosion pit		Replace with new pinion	Install out-of-spec part	Make no QA checks
	high impact force on area	jammed solid	Remove solids			
		excessive start-up load		Limit start-up load	Start-up under full load	No operating standards
		cummulative forces (misalign,	Prove precision assembly and	installation engineering standa	Install outside precision stand:	Make no QA checks
		induced vibration	Remove causes of induced vibration		Install outside precision standards	Make no QA checks
		softfoot distortion	Prove equipment bases and base plates are flat to the manuf		Install outside precision stand:	Make no QA checks
		chipped teeth reduce area		Replace with new pinion	Install out-of-spec part	Make no QA checks
helical gear wheel						

Figure 12 Recognising Human and Business Factors Contributing to Equipment Failure

With this comprehensive list of issues related to component failure you are in an excellent position to do something about improving the reliability-impacting practices in your operation.

Step 8: Allocating Responsibility to do Strategy Requirements

Each chosen preventive action is done by the people most appropriate in the organisation to do it. These people have the competence to do it correctly and do it well. In Figures 11 and 12 the preventive actions listed are allocated between Engineering (yellow), Operations (amber) and Maintenance (green). Some requirements are shared across groups depending on where in the equipment life cycle that issues can arise to later cause operational equipment failure.

You are now starting to build the business-wide processes that will change the operation and deliver the reliability you want from your equipment. You are designing the future business and operations system that will take your company to operational excellence and world class operational performance. From this allocation of responsibilities will flow the necessary engineering and precision standards to be met throughout the life cycle, the necessary supporting documents you need in each department, the necessary technical knowledge, skills and competence needed by your people, the training needs for your people, the recording and reporting systems that confirm the strategies are being delivered correctly in your business unit, and so on throughout the organisation.

The Plant and Equipment Wellness methodology helps you to build the least number of the right processes and actions that build you a high reliability operation.

Step 9: Confirming Economic Value of New Strategy

The final step is to prove the chosen actions will deliver great value to the business. As shown in Figure 5, the risk matrix is used to identify the effect of the changes on equipment reliability and the quantum of new profits made once the improvements are implemented and in use.

You are comparing the risk level in the business today for the piece of equipment under review to the risk that will result if the reliability improvement changes identified in the analysis become standard operating practices.

For mitigations to be acceptable your selection must pass the two rules that determine the size of the future business risk.

- 1. A mitigation that reduces likelihood is acceptable if and only if it significantly reduces the stress in a part.**
- 2. A mitigation that reduces consequence is acceptable if and only if it significantly reduces the consequential cost should the failure event initiate.**

On the risk matrix you locate the likely future business risk zone to confirm the mitigations will bring clear value to the business.

Conclusion

The calibrated risk matrix is a true representation of the business behaviour and we use it to make sure that any risk mitigation suggested will in fact deliver real benefits to the business. Unlike FMECA / RCM where there is no idea if a maintenance activity actually benefits the business or merely adds cost without benefit, the calibrated risk matrix makes it clear to all if doing a mitigation will truly deliver real business profit.

You now have a standard process for delivering exceptional equipment reliability and maximum life cycle profits from operating assets.

Best regards,

Mike Sondalini
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