# Design-Out Maintenance as a Crucial Maintenance Facet

**Peter Muganyi**
Department of Engineering Management
University of Johannesburg
Johannesburg, South Africa
peter777.muganyi@gmail.com

**Charles Mbohwa**
Faculty of Engineering and the Built Environment
University of Johannesburg
Johannesburg, South Africa
cmbohwa@uj.ac.za

**Ignatio Madanhire**
Department of Mechanical Engineering
University of Zimbabwe, P.O Box MP167
Harare, Zimbabwe
imadanhire@eng.uz.ac.zw

## Abstract

In many instances, maintenance engineers arrive at a point where the maintenance decision calls for the redesign of the physical asset in order to address the reliability issues encountered during the course of operating and maintaining the asset. One of the most effective and broadly applied techniques is Design-Out Maintenance (DOM) and many researchers in Maintenance Management have alluded to this technique as highly effective and widely applied in the field of asset maintenance. The drivers for physical assets modifications are diverse and situational as various factors are considered when it comes to such endeavour, and the cost of the modification or re-design being one of them. A systematic approach to this engineering phenomenon is imperative to give guidance and credence to this noble approach, followed by evaluation techniques for the effectiveness of the exercise. This study pursued an industrial set-up analysis to examine the pros and cons of the DOM technique.

## Keywords
Design-out, systematic, modification, technique

## 1. The triggers for design-out maintenance

There exists in the world of asset maintenance a practice that is referred to as "Improvement Maintenance" whose chief objectivity is to curtail recurrent asset failures, through application of comprehensive investigations and the unravelling of failure causes and then prescribing sustainable counter measures to prevent repetition of failures (Danish and Siddiqui, (2016:5). The resultant counter measures may possibly necessitate considerable design changes to an asset with the aim to eliminate the prevailing failure patterns; and design-out maintenance is the maintenance strategy that is used in cases where it is obvious that the existing design is not capable of withstanding or muddle through the expected reliability standards (Danish and Siddiqui, 2016:5). A life-time-extension tactic can also be deployed as asset care engineers assess options to elongate equipment life by subjecting it to modifications to its structure, materials of construction or augmentations by applying the likes of protective layering (Danish and Siddiqui, 2016:5). Failures riddance is a crucial aspect of Improvement Maintenance, and all functional failures should be regarded as prospects for reliability amelioration with sustaining actions modelled relative to the failure cause findings. Considering the maintenance approaches available to asset intensive industries, three dominant strategies stand out, and these are life improvement, proactive and reactive maintenance strategies, whereby the life improvement maintenance strategy encompasses the re-design of an asset assembly or a component as a means to eradicate recurrent malfunctions, and this is also alternatively referred to as design-out maintenance (Burnett and Vlok, 2014:164). Figure 1 below displays the significant position that Improvement Maintenance exhibits as part of the maintenance program.

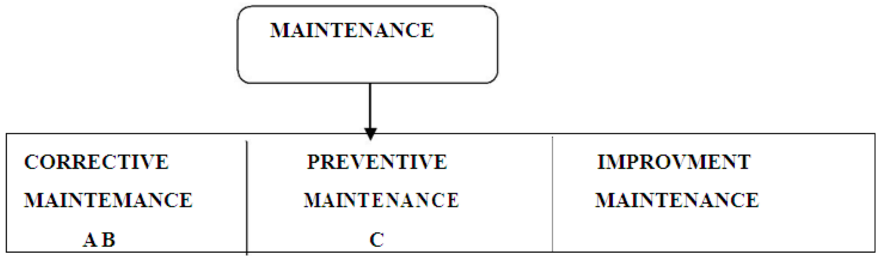


Figure 1. Maintenance program depicting Improvement Maintenance significance (Danish and Siddiqui, 2016:3)

The operational and asset care expenses have a positive or negative impact on a business' continual existence in the current harsh environments where high demands are placed on the business performance aspects like throughput, reliability, quality offerings, profitability, and safety or environmental compliance (Waeyenbergh and Pintelon, 2004:395). Maintenance slants to improve reliability of physical assets, and therefore availability, is broadly applied in manufacturing industries, and in conjunction with other maintenance interventions, design-out maintenance is prevalently applied to improve physical assets' reliability in the operational environment (Waeyenbergh and Pintelon 2004:395, Faccio et al 2014:86).

## 2. Major tenets of design-out maintenance

Processes such as the Management of Change have been adopted to cater for the likes of asset design alterations under the auspices of Improvement Maintenance, and this essentially calls for the process of design changes to the asset to eliminate reliability issues previously encountered, hence Improvement Maintenance is essentially **design-out maintenance**. Design-out maintenance is a strategy that aims for improvement rather than just conducting maintenance activities to ensure system functionality, and its focus is the improvement of system design to reduce the maintenance burden or even eliminating maintenance altogether (Ding and Kamaruddin 2015:1264). Re-designing of improved ergonomics of systems for operational and asset care workforces is also another prerogative of design-out maintenance, and it is no doubt that because of these high expectations placed on design-out maintenance, this strategy calls for high levels of knowledge and expertise as well as the requisite training (Ding and Kamaruddin, 2015:1264). Management of Change in the work place is mostly rooted in the process safety management arena which entails risk-based decision-making strategies as a means of verification of the modification to desired risk levels, of which the assessment criteria usually apply a quantitative approach that hardly incorporate time-dependent events, and oftentimes missing the dynamic aspects (Demichela, et al 2017:14873).

A depiction of a general arrangement of a management of change process is illustrated in Figure 2 below.

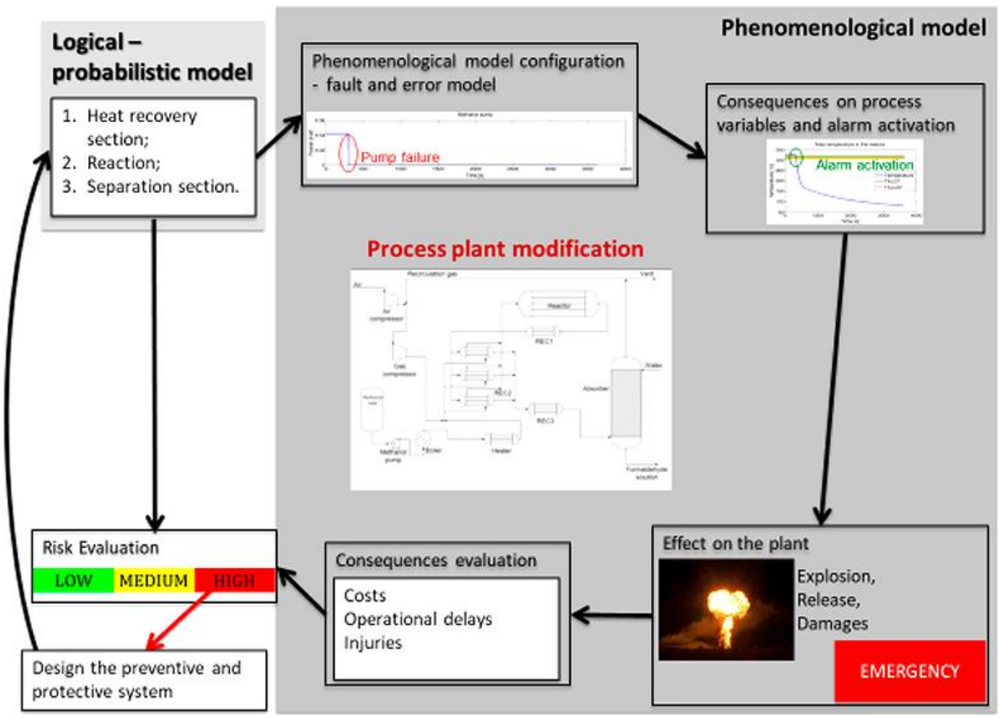


Figure 2. A depiction of a Management of Change process (Demichela et al 2017:14874)

Figure 3 below shows that Design-out Maintenance is indeed an improvement strategy which can be applied effectively for physical assets reliability increase.

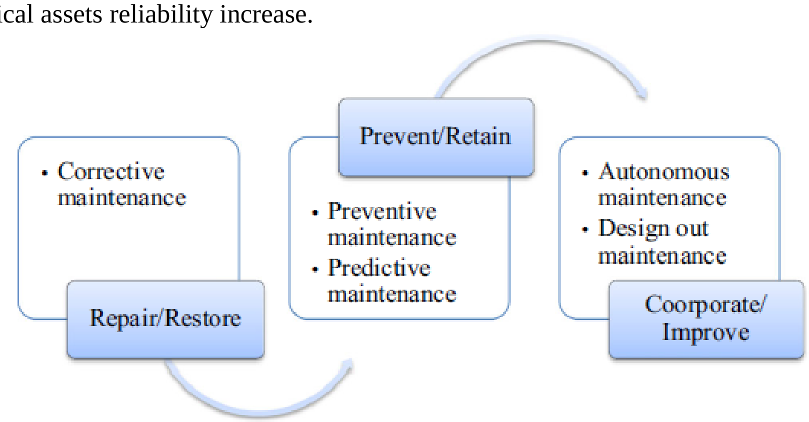


Figure 3. Design-out Maintenance depicted as an Improvement Strategy (Ding and Kamaruddin 2015:1264)

Design-out maintenance is a strategy that aims for improvement rather than just conducting maintenance activities to ensure system functionality, and its focus is the improvement of system design to reduce the maintenance burden or even eliminating maintenance altogether (Ding and Kamaruddin 2015:1264). Re-designing of improved ergonomics of systems for operational and asset care workforces is also another prerogative of design-out maintenance, and it is no doubt that because of these high expectations placed on design-out maintenance, this strategy calls for high levels of knowledge and expertise as well as the requisite training (Ding and Kamaruddin 2015:1264). Design-out Maintenance aims to eradicate the sources of reliability decline as a consequence of functional failure or deterioration, and then improving reliability to attain the targets set as the prevailing maintenance program. Relatively sliding surfaces are always subjected to frictional and wear losses culminating in the loss of energy and economic usefulness, and refurbishment actions aimed at restoration of usefulness levels is prevalent in the industrial setup (Wang, et al 2017:351). Some refurbishment activities encompass significant design changes to address prolonged useful life of components, and this is done under the auspices of Design-out Maintenance (Wang, et al 2017:352). The implementation of Design-out Maintenance entails appraisal of issues that incorporate the assets' materials-of-construction, structural designs, precision assembly, component sizing, stress reduction and elimination etc., all done in the name of heightening asset reliability. Design-Out Maintenance's emphasis is on the refinement of the physical asset to minimize investment in maintaining the asset over time and thereby drastically reducing the liability of maintenance all the way through the life-cycle of the asset (Mostafa, et al., 2015:240). Design-Out Maintenance is premised on the culminating design modifications emanating from the asset care information and knowledge obtained over a period of its operational life and design-out maintenance is appropriate for equipment with colossal maintenance outlays emanating from defective designs or assets operating outside their design specifications (Mostafa et al 2015:240).

The deployment of a maintenance strategy is to harness optimal asset performance and ensuring a balance between maintenance expenditures and reliability aspects, coupled with interrelated factors that are simultaneously considered (Ding and Kamaruddin 2015:1263). Design-out maintenance as an intervention does not operate in isolation from other maintenance strategies, but it is rather effective in complementing other conventional maintenance strategies such as Preventative-Maintenance, Corrective-Maintenance and Predictive-Maintenance. It is easily assimilated into strategies such as Reliability-Centered-Maintenance (RCM), Total-Productive-Maintenance (TPM) and World-Class-Maintenance (WCS). The fluctuating pattern of manufacturing entities render it impossible for enterprises to rely on a singular maintenance strategy that fully meets the maintenance requirements of its physical assets, and a compendium of maintenance strategies is the norm for optimum asset maintenance (Ding and Kamaruddin 2015:1263). Figure 4 below illustrates the relation of design-out maintenance with other conventional maintenance strategies, showing its significance in the improvement of physical asset reliability.

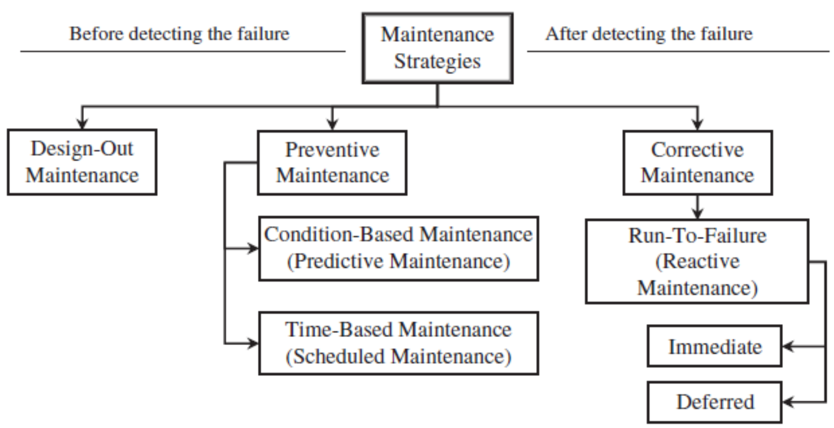


Figure 4: Design-Out maintenance in conjunction with conventional maintenance strategies (Mostafa, et al 2015:239)

## 3. Strategic application of design-out maintenance

Design-out maintenance has been utilized with great success in various industries to avert catastrophic and costly failures and its application is quite broad and ranging from chemical industries to automotive industries. In one particular instance, a design-out maintenance strategic methodology was applied to eliminate false-brinelling in a wind turbine resulting in a patented design for the wind turbine and as illustrated in Figure 5.

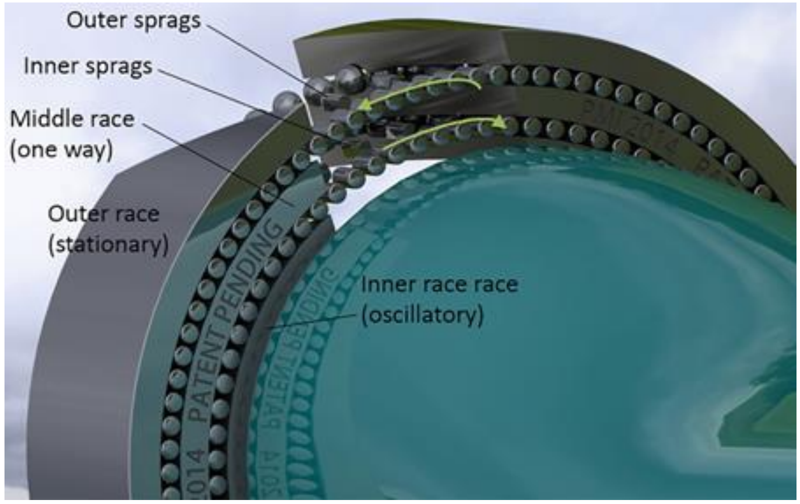


Figure 5: A wind turbine modified to avert false-brinelling (Plymouth Machine Integration, 2017)

Another typical patented design-out maintenance success outcome is registered under Patent Number: 8,033,782 in the United States of America and it refers to a design modification of a slot and pin assembly to avert false-brinelling (Knotek 2016:79). Design-out maintenance results mostly from failure investigations with resultant counter measures or sustaining actions that eradicate recurring failures through asset design modifications, and resultantly reliability. The key target is removing the source of malfunctions in an asset and to introduce improved reliability.

Construction materials of industrial assets are also modified through the design-out maintenance strategy to introduce stronger, more durable or high performance structures that can withstand the harsh operating conditions. Techniques such as composite surface engineering technologies are applied to alternately deposit nanoscale multilayer metal films (Fe/Mo, Fe/W, W/Mo, etc.) by the likes of dual-target magnetron sputtering technology to produce friction-pair surface performance coatings (Wang, et al 2017:352). A depiction of the coating process is shown in Figure 6 below.

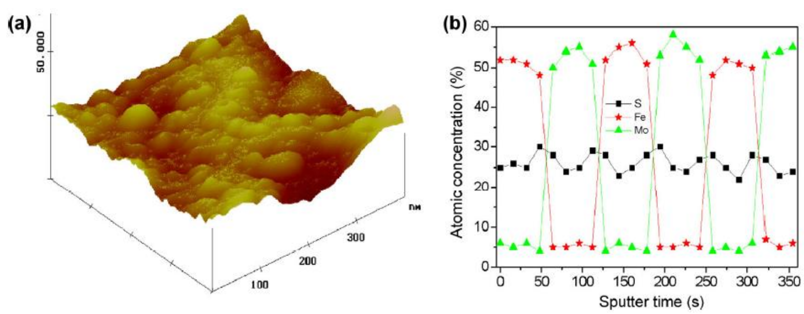


Figure 6. Surface Morphology (nano-multilayer film) and element distribution with surface-coating of $FeS/MoS_2$ multi-layer films (Wang et al 2017:353)

Plasma-spraying technology has been effectively applied to form high-quality wear-resistant and anti-fatigue integrative coatings. The plasma-sprayed coatings have displayed exceptional wear-resistance aspects in sliding components, but the deposition method of the coating that defines its microstructure embroils numerous interfaces with the key to increase the wear-resistance and fatigue-resistance capabilities of the plasma-sprayed coatings synchronously being to augment the bond-strength and cohesion-strength of the coatings (Wang et al 2017:356). The Figure 7 below shows the surface morphology and friction coefficients of plasma-sprayed coatings.

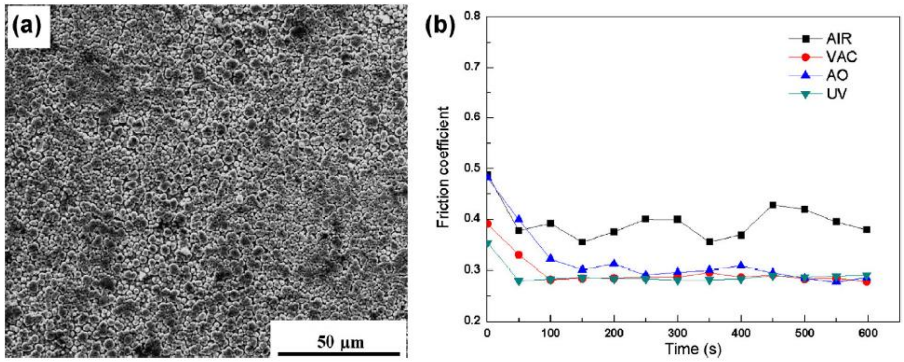


Figure 7: Surface morphology and friction coefficient of plasma-sprayed coating (n-$Al_2O_3$/Ni/In.) (Wang, et al., 2017:357).

The design-out maintenance strategy is applied on any industrial equipment, for instance, the design modification of a recuperator to improve performance and reliability, and this is illustrated by a case study carried out by Ludwig and Zając (2017: 567) who applied conceptual work fixated on defining different geometrical dimensions to certify even gas drift in the recuperator inter-pipe space, to condense the dimensions and mass of the equipment, and ultimately improving the reliability.

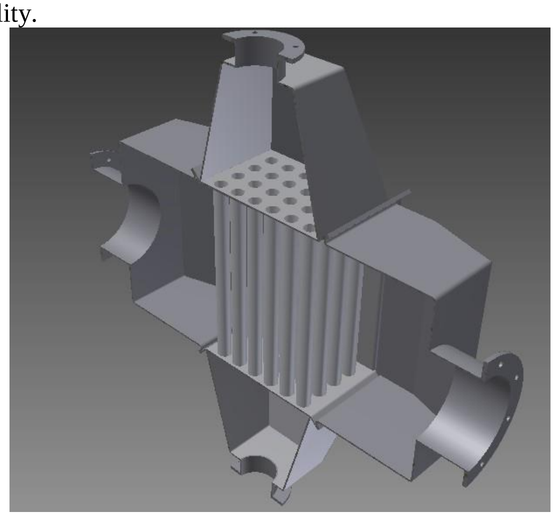

Figure 8.Illustrative design of a recuperator (Ludwig and Zając 2017: 568)

Techniques like computational fluid dynamics (CFD) were applied to formulate modification options (Ludwig and Zając, 2017: 567). This shows that design-out maintenance as a strategy incorporates a myriad of tools to advance its cause of equipment improvement in relation to reliability.

## 4. Case study on application of design-out maintenance

A pulp and paper manufacturer in Johannesburg, South Africa had one of its pulp chests equipped with horizontally mounted agitators, which had gland packings as the static sealing mechanism around the agitator shafts to prevent loss of pulp from the pulp chest. A design-out maintenance approach was taken to accomplish a functional system design modification in order to prevent the frequent gland packing failures that were experienced around the machine chest agitators. The issues encountered were as follows:

- ❖ Gland leaks around the agitators that were experienced at least once every week during machine operation. The objective was to prevent gland leaks for a minimum of 4 weeks after new gland packing installation

The design- out maintenance considerations had to consist of the following issues:

a. Current maintenance practices around gland packing
b. Proposed new dimensions of equipment around gland packings
c. Alternative static sealing arrangements for the agitator shafts

The picture below shows the general arrangement of the agitators' installation on the chest.

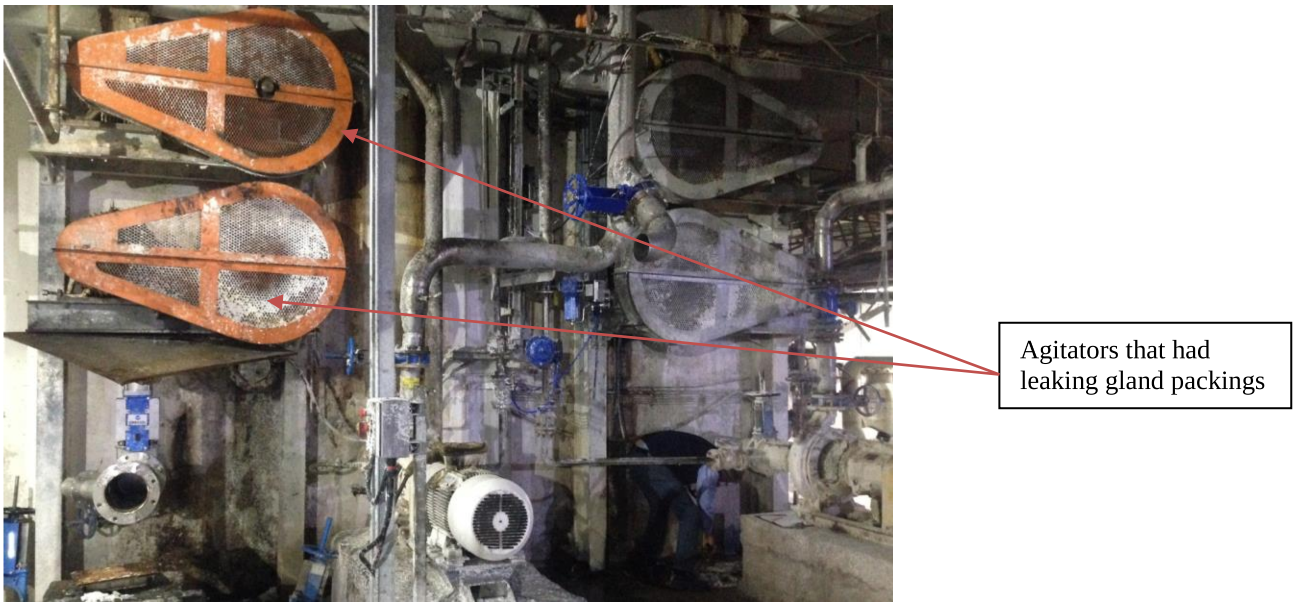


Figure 9. General arrangement of agitators on pulp chest (Muganyi, 2017)

### 4.1 Prevailing maintenance practices

The maintenance work pertaining to static sealing that was being carried out around the agitators involved the following aspects:

- ❖ Packing change
  - a. Packing size used = 16mm
  - b. Type of packing material – graphite
  - c. Stuffing box ID = 121mm
  - d. Shaft OD = 75mm
  - e. Stuffing box sleeve OD = 141 mm
  - f. Number of rings for new packing = unknown
  - g. Length of packing ring = 200mm
- ❖ Packing adjustment
  - a. Pulling up glands
- ❖ Pulley removal
- ❖ Machine guard removal
- ❖ Bearing housing replacement
- ❖ Bearing removal
- ❖ Bearing installation.

### 4.2 Failure analysis for design-out maintenance

An analysis of the possible causes of the static packing failures was undertaken to establish the causes of the failures and the general guidance was taken from the table below.

Table 1. Possible causes of gland packing failure and solution proposals

| | | |
|---|---|---|
| Pump takes too much power | Packing too tight | Release gland pressure. Retighten reasonably. Keep leakage flowing-if none; check packing, sleeve or shaft. |
| Pump leaks excessively at stuffing box | Defective packing | Replace worn packing. Replace packing damaged by lack of lubrication. |
| | Wrong type of packing | Replace packing not properly installed or run-in. Replace improper packing with correct grade for liquid being handled. |
| | Scored shaft or shaft sleeves | Put in lathe and machine true and smooth or replace. |
| Stuffing box overheating | Packing too tight | Release gland pressure. |
| | Packing not lubricated | Release gland pressure and replace all packing if any burnt or damaged. |
| | Wrong grade of packing | Check with pump or packing manufacturer for correct grade. |
| | Insufficient cooling water to jackets | Check if supply line valves opened or line clogged. |
| | Stuffing box improperly packed | Repack |
| Packing wears too fast | Shaft or shaft sleeve worn or scored | Re-machine or replace. |
| | Insufficient or no lubrication | Repack and make sure packing loose enough to allow some leakage. |
| | Improperly packed | Repack properly making sure all old packing removed and box clean. |
| | Wrong grade packing | Check with pump or packing manufacturer. |
| | Pulsating pressure on external seal | Makes packing move and prevents it taking a 'set'. Remove cause of pulsation. |

A root cause analysis was done and the main causes of the gland packing failures were unveiled as: wrong grade/type of packing applied relative to static pressure, packing size cross-section was incorrect and cut ring length was incorrect. Applying the general compression packing formulae adopted from packing seals suppliers, the sizing of the static gland packings was calculated as follows:

***1. Packing size cross section***

a. Packing Size = (OD – ID)/2

b. Stuffing box inner diameter = OD = 121mm

c. Agitator shaft Outer diameter size = ID = 75mm

d. The design packing size = (121 – 75)/2 = **23mm**

Therefore, the selected size of **16mm** packing was grossly undersized for this application and bigger size packings were required for the application.

***2. The cut ring length*** was calculated according to the following formula

a. Cut ring length = (ID + OD X $\pi$)/2 + 1.3%

Where: -

i. OD = Stuffing Box Bore Diameter (mm) &

ii. ID = Stem or Shaft Diameter (mm)

Therefore, the required cut ring length is $(121 + 75 \times \pi)/2 + 1.3\%$ = **180.6 mm**.

It was established that the cut ring length of 200mm that was being used was oversized and this compromised effective packing of the gland inside the stuffing box.

***3. pH values***

The pH value in the pulp chest was established to be around 7 ~ Neutral, and the selected gland packing material was confirmed to be suitable for the operational conditions of the agitators

***4. Stuffing box pressure (SBP)***

The stuffing box pressure was calculated according to the following formula

a. SBP = PS + [25% (TDH)]

Where: -

i. PS = Pump Suction Pressure &

ii. TDH = Total Dynamic Head

The total dynamic head was found as = $\rho\ g\ h$

Where $\rho$ (pulp density) = 1000 kg/m$^3$

$g$ = 9.8 m/s$^2$ and h (height of chest from agitators level) = 7m

TDH = 1000 x 9.8 x 7 = 68 600 pascals = 0.686 bar

The pump suction pressure = 0 bar since it was only the static pressure due to pulp that was acting on the agitator seals.

SPB = 0 + 0.25 x 0.686 = **0.1715 bar**

Considering a safety factor of 3, the pressure rating of the static seals was found to be inadequate, and a sealing arrangement that could withstand higher pressure was recommended.

***5. Shaft speed conversion meters per second (m/s)***

The shaft speed conversion which is derived from the formula below was not analyzed due to its insignificance as recommended based on expert opinion on the problem at hand.

m/s = (π)(D s )(RPM) 60,000 max.

m/s = ( RPM )(D s ) 19,100 max

Where: -

i. Ds = Shaft Diameter (mm) &

ii. RPM = Revolutions per Minute

## 4.3 Static sealing alternatives and implemented solutions

Three main solutions to the problem were considered and these were the options availed.

1. Installation of mechanical seals in place of static gland seals,

2. Installation of gland packing seals only according to the correct sizes as derived from the root cause analysis,

3. Installation of a combination of a lantern ring and gland packing seals. The final proposed and implemented solution according to the design-out maintenance strategy included the following:

a. Installation of a lantern ring

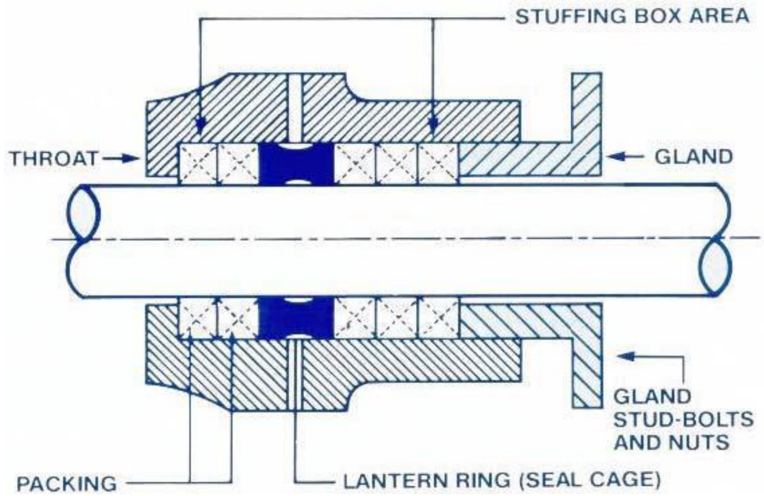


Figure 10. General arrangement of a lantern ring seal assembly (Muganyi 2017)

This option was selected as it could withstand the operational environment dynamic pressure and could adversely reduce leakage when properly installed and used in conjunction with static gland packing.

b. Correct packing material size selection based on PH, temperature and pressure values. The selected material size was centered on the 23mm packing size as per the derived required size.
c. Correct alignment and centering of shaft during installation – use of jacking bolts and laser alignment.
d. Correct packing cut ring length based on the calculated size of 180mm.

## 5. Discussion of design-out maintenance implementation results

After implementation of the recommended solutions as stated in the sections above, the performance derived from the pulp chest agitator with regards to the static gland packing seals was as follows:

- The gland packing seal leakages were experienced after 8 weeks compared to 1 week previously
- The cost of product loss and maintenance time was reduced by over 80%
- The design-out maintenance strategy that was applied to solve the problem of high frequency of failure of the agitators' gland packings was effective in improving the MTBF (1 week to 8 weeks) and therefore improving reliability.

This research revealed that design-out maintenance does embrace different techniques and technologies to attain the desired results, and the broad types of design out maintenance can involve, among other aspects such as structural design changes, material of construction changes, dimensional changes, environmental change, technological changes, coating changes and throughput performance changes.

## 6. Conclusion

Design-out maintenance strategy is still being applied by many industrial establishments and it is effective in improving equipment reliability when it is applied correctly. The case study results have shown that for deriving design-out maintenance benefits, firstly a structured methodology for understanding the root cause of failures is imperative before embarking on a design-out exercise. Secondly, the alternative solutions options need to be assessed and an optimum solution need to be reached on based on a systematic selection criteria. This will prevent a repeat of the same exercise on a solution that has already been implemented. Thirdly, the design-out maintenance strategic implementation results need to be measured and compared against the established project objectives and the results should be used as learnings for future projects or endeavors.

Future research efforts should focus on the relevance and the wide systematic application of design-out maintenance as an effective reliability improvement intervention.

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## Biographies

**Peter Muganyi** is a Doctoral Candidate in Engineering Management at the University of Johannesburg, South Africa and he is an Engineering Manager at Gyproc. His research interest covers the areas of Lean Six Sigma effectiveness, Strategic Maintenance Systems deployment and Business Process Modelling.

**Professor Charles Mbohwa** is the Vice-Dean Postgraduate Studies, Research and Innovation at the University of Johannesburg's (UJ) Faculty of Engineering and the Built Environment (FEBE). As an established researcher and professor in the field of sustainability engineering and energy, his specializations include sustainable engineering, energy systems, life cycle assessment and bio-energy/fuel feasibility and sustainability with general research interests in renewable energies and sustainability issues.

**Ignatio Madanhire** graduated with a PhD in Engineering Management at the University of Johannesburg, South Africa, where he is also a Senior Research Associate. He is also a Senior Lecturer with the Department of Mechanical Engineering at the University of Zimbabwe. He has research interests in Engineering Management and has published works on cleaner production in renowned journals.