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RECIPROCATING PUMPS: System Modification for Maintenance IMPROVEMENT

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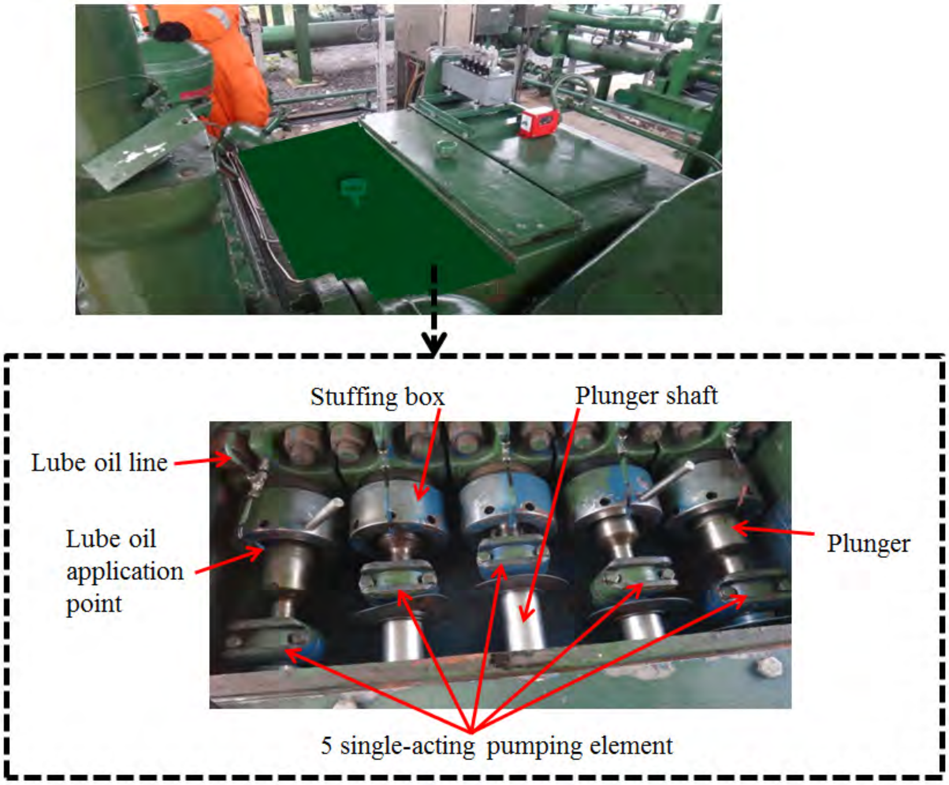

Figure 1: Spiking pump (SP) at the plant

System modification is an economically viable option to restore mechanical integrity, achieve optimum operation and reduce maintenance costs. This is realized through the development of a system modification program for a reciprocating pump with recurring leakage failures.

Introduction

Energy companies are actively seeking cost-effective alternatives to high cost items and/or processes. This article demonstrates how a cost-effective remedial solution for a recurring leakage failure of a reciprocating pump was established through the development of a system modification program. This program was strategically formulated by coalescing different maintenance techniques, processes and tools.

Case Study

A reciprocating pump in an oil and gas plant, referred to as a spiking pump (SP) in this article, was used in the transfer of condensate from a condensate tank into a gas pipeline (see Figure 1).

Prior to deploying the SP into service, an energy company had sustained significant financial

Table 1: Spiking Pump Technical Specifications

Criteria	Detail
Manufacturer	National Oilwell Varco (NOV)
Pump type	Quintuplex plunger pump
Pump model	300Q-5L
Drive type	Oil lubricated crank drive
Power source	Electric motor
Plunger diameter	2.75 in (69.8 mm)
Plunger stroke length	5 in (127 mm)
Weight of SP	7000 lbs. (3175 kg)
Pump speed	1105 rpm
Power (at 400 rpm)	300 hp (224 kW)
Suction pressure	13.1 psi (90 kPa)
Discharge pressure	1340 psi (9240 kPa)
Pumping temperature	200°F (93.3°C)
Volumetric flow rate (at 400 rpm)	257.1 gpm (973.2 l/min)
Designed for (application)	Oil service

losses and extended business interruptions from sabotages on its condensate pipelines. Through efforts to mitigate these losses, it established a process change. The process change entailed transporting condensate as a mixture with natural gas in its gas pipelines. To implement this process change, a reciprocating pump was needed to inject condensate from the condensate tank into the gas pipeline to meet the high discharge pressure requirement.

A reciprocating pump was available, however, it was designed for oil service. A reciprocating pump conducive for condensate service was unavailable and had a 48 weeks lead time to supply. Since condensate sales were a major income stream for the energy company, procurement was not viable. The available SP was deployed for condensate service. However, this change initiative was not governed by management of change (MOC). The technical specifications of the SP are shown in Table 1.

Being a quintuplex pump type, the SP had five single-acting pumping elements. It uses five parallel cylinders acting in timed sequence to smooth the output pressure pulsation. The SP has a high pumping capacity because of its multiple plungers. Quintuplex and triplex pump types have the same components; the only variation is the number of single-acting pumping elements. Based on this fact, a 3-D model of a triplex pump was used to enhance insight on the components of the SP (see Figure 2).

The Problem

The process change was effective in eliminating all financial losses (i.e., about $15 million a year) stemming from condensate pipeline sabotages. However, the process change caused unreliability in the condensate service system. The SP had recurring leakage of condensate from its gland packing, with mean time between failures (MTBF) of five days or about 120 running hours. Consequently, the SP's unreliability had financial implications: maintenance costs of $360,000 a year for routine replacements of gland packing and production loss of $720,000 per day for unplanned downtimes.

Investigation

An investigation was undertaken to ascertain the root causes of the SP's recurring leakage failure. Figure 3 shows the overall summary of the investigation process that was used to identify the root causes of the leakage failure and ascertain the best remedial route that was technically feasible and financially viable.

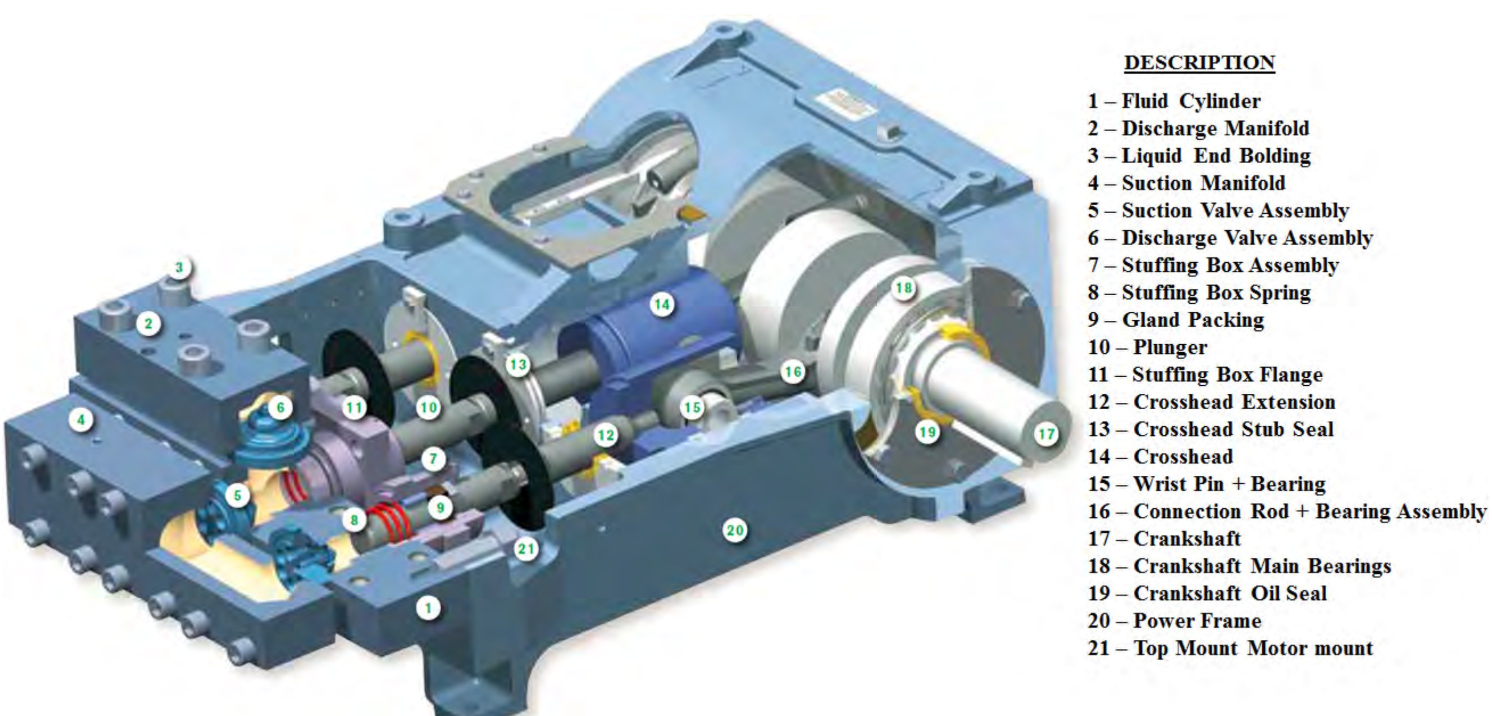

Figure 2: 3-D model of a reciprocating pump (Source: Reciprocating Pumps; SPX, 2012)

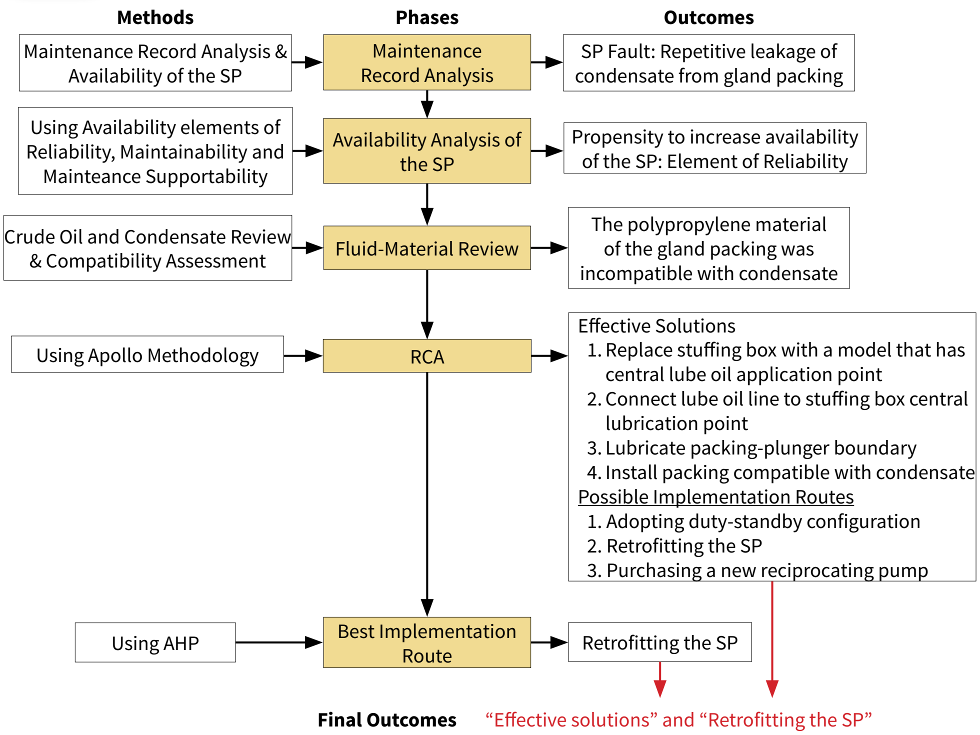

Figure 3: Investigation process for SP's recurring leakage failures

The maintenance record of the SP was extracted from the computerized maintenance management system (CMMS). An analysis of the maintenance record authenticated that the recurring leakage of condensate from the gland packing was the prime failure of the SP.

The unreliability of the SP was a consequence of its recurring leakage failures, thus, its current operational availability was below the baseline. To resolve this, an availability analysis was performed to identify the direction in which to seek solutions. The relationship between elements and availability performance were identified as follows:

- **Technical System** — Reliability and Maintainability
- **Maintenance System** — Maintenance Supportability

These three elements – reliability, maintainability and maintenance supportability – were used to drive the availability analysis. Availability analysis results determined that the most effective improvement initiatives for the SP would be found in the element of reliability. Therefore, remedial solutions were formulated with a prime focus on reliability.

A fluid material review was undertaken to review the properties of condensate, ascertain its impact on the SP's internal components and assess its compatibility with the materials of the internal components. The outcome of this review affirmed the incompatibility of the gland packing material (i.e., polypropylene) and condensate.

Root cause analysis (RCA), being an effective tool for cause and effect analysis, was used to identify the root causes of the leakage failure and effective solutions that would permanently remediate the failure. The Apollo RCA methodology was adopted because it produced an evidence-based understanding of the recurring leakage problem. It was ascertained that the plunger was running dry through the gland packing, causing rapid wear of the packing materials. This wear propagated clearances, leading to significant leakage of condensate through the packing gland.

From all the findings, the following were established as root causes for the recurring leakage failure:

- No central application point for the lube oil;
- Gland packing material was in direct contact with the plunger;
- Polypropylene gland packing material was incompatible for condensate service.

From these root causes, the effective solutions formulated were:

- Replace stuffing box with a model that has a central lube oil application point;
- Connect lube oil line to stuffing box central lubrication point;
- Lubricate packing plunger boundary;
- Install packing compatible with condensate.

The potential implementation routes for these effective solutions were established as:

- Option 1 – Adopting a duty/standby configuration for the SP;

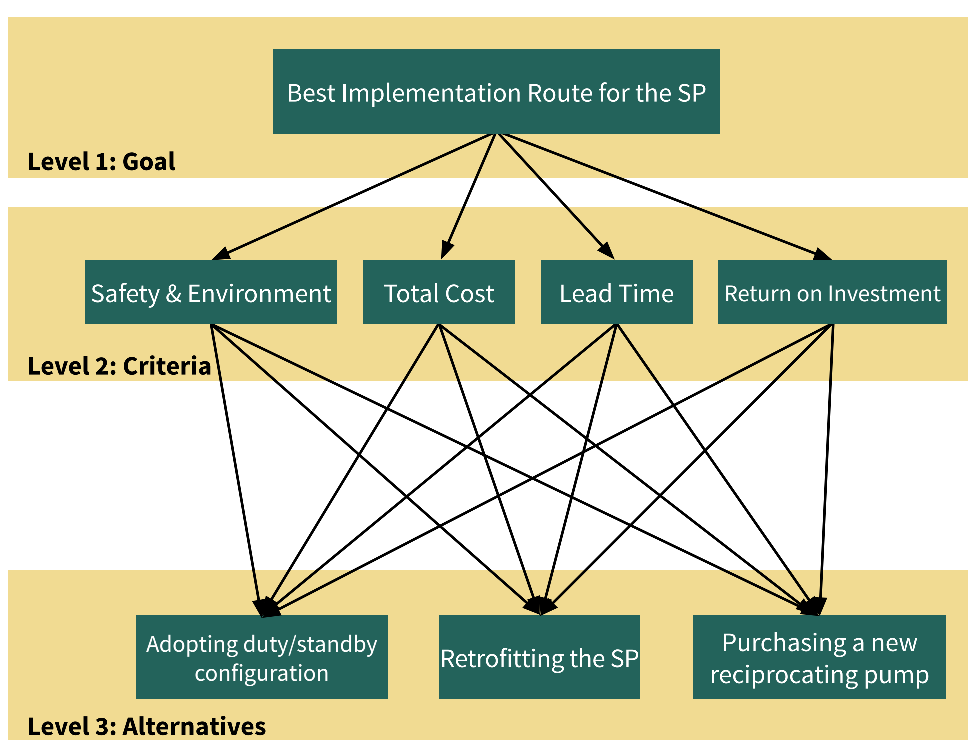

Figure 4: AHP decision model for best implementation route

- Option 2 – Retrofitting the SP;
- Option 3 – Purchasing a new reciprocating pump.

These established implementation routes were subjected to multiple criteria decision-making (MCDM) using analytic hierarchy process (AHP) to ascertain the best implementation route as shown in Figure 4. The multiple criteria included:

i. Safety & Environment – zero accidents, zero incidents and zero loss;
ii. Total Cost – all direct and indirect costs involved;
iii. Lead Time – the time frame between initiation and completion;
iv. Return on Investment (ROI) – the financial benefits and economic gain.

A pairwise comparison of criteria with respect to goal was performed. Furthermore, a pairwise comparison of alternatives with respect to each criterion was performed. This yielded a comparison matrix with composite weights for each criterion/alternative combination.

Retrofitting the SP emerged with the highest overall score (composite weight) in the comparison matrix, making it the most technically feasible and financially viable implementation route.

System Modification Program

To restore mechanical integrity to the SP and reduce its maintenance cost, a system modification program was developed. The development of the program was based on effective remedial solutions and best implementation route.

To effectively encompass all essential attributes required for the development of the system modification program, a one layer CIMpgr process model was adopted to model the system modification program. A CIMpgr process model is a graphical diagram that illustrates object to object relationships, their functions and entities, and gives better insight on data flow by classifying them into inputs, outputs, resources and controls. Figure 5 delineates the CIMpgr process model for the system modification program. The CIMpgr model articulated all inputs, controls, resources and outputs (ICRO) variables and provided a holistic line of sight for the system modification program.

The backbone of the system modification program was a 3M process: modification, monitoring and maintenance. The system modification program model is shown in Figure 6.

The modification element of the 3M process encompassed the redesign of the SP's stuffing box in accordance to the remedial solutions, as well as the selection of a new gland packing material, which was compatible with condensate. The current and redesigned SP stuffing box are compared in Figure 7. A square ring (i.e., packing style) braided aramid fiber with a lubricant coating (i.e., material) was the selected gland packing material because it was compatible for either condensate or oil service.

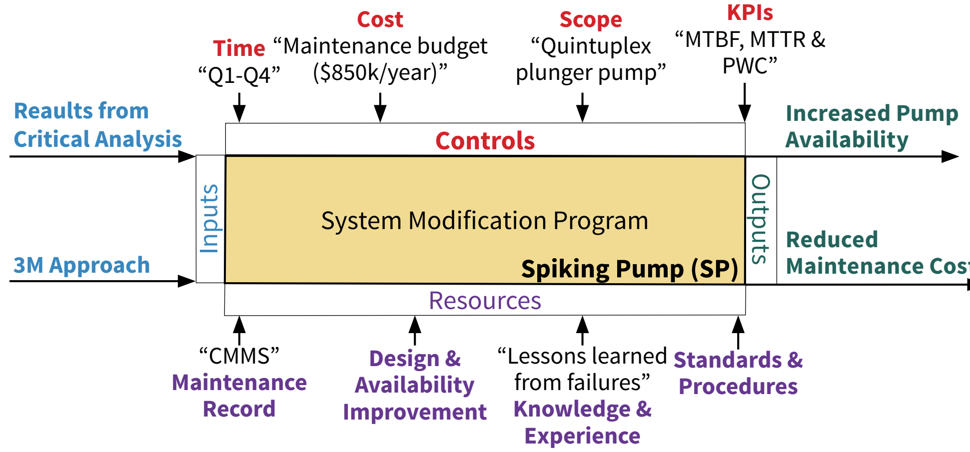

Figure 5: CIMpgr process model for the system modification program

With the current stuffing box, when the plunger undertook a suction stroke, lube oil was drip fed on the plunger, as per original design for oil service. During the discharge stroke, the high viscosity of the oil (i.e., the pumped fluid) was supposed to slightly oppose the movement of the plunger. This opposition was to reduce the speed of the plunger and facilitate lube oil smearing, resulting in good lubrication at the packing plunger boundary. However, in its present application for condensate service, due to the low viscosity of condensate, there was minimal opposition to the plunger movement. The lube oil, which was drip fed on the plunger, was scraped off by the first packing ring of the gland packing. This resulted in poor lubrication at the packing plunger boundary, high friction between the packing and plunger, and packing and plunger wear.

With the redesigned stuffing box, the lube oil application point is at a central end. During the suction and discharge strokes, lube oil is drip fed on the gland packing to soak it. Based on the fact that the gland packing will always be soaked when the plunger passes through, a significant increase in lube oil smearing efficiency on the plunger is realized. This results in good lubrication at the packing plunger boundary and insignificant friction between the packing and plunger.

The monitoring element encompassed a condition monitoring (CM) system developed for the SP to facilitate a proactive maintenance approach. The selected techniques for monitoring were pressure and visual inspection. The operation limits – baseline, alarm and trip – were established for each parameter.

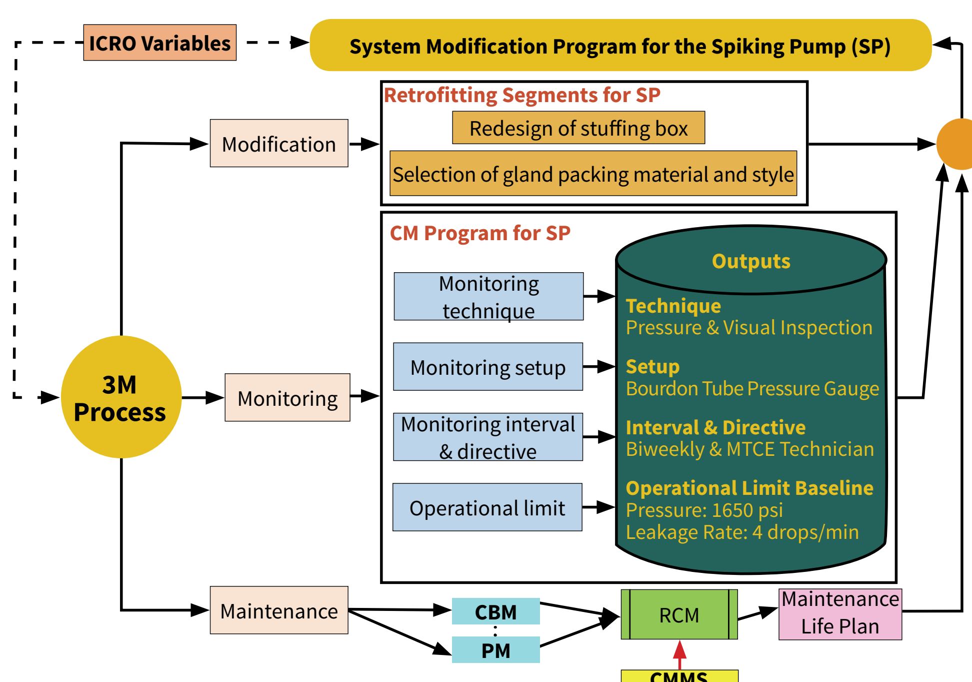

Figure 6: System modification program model for the SP

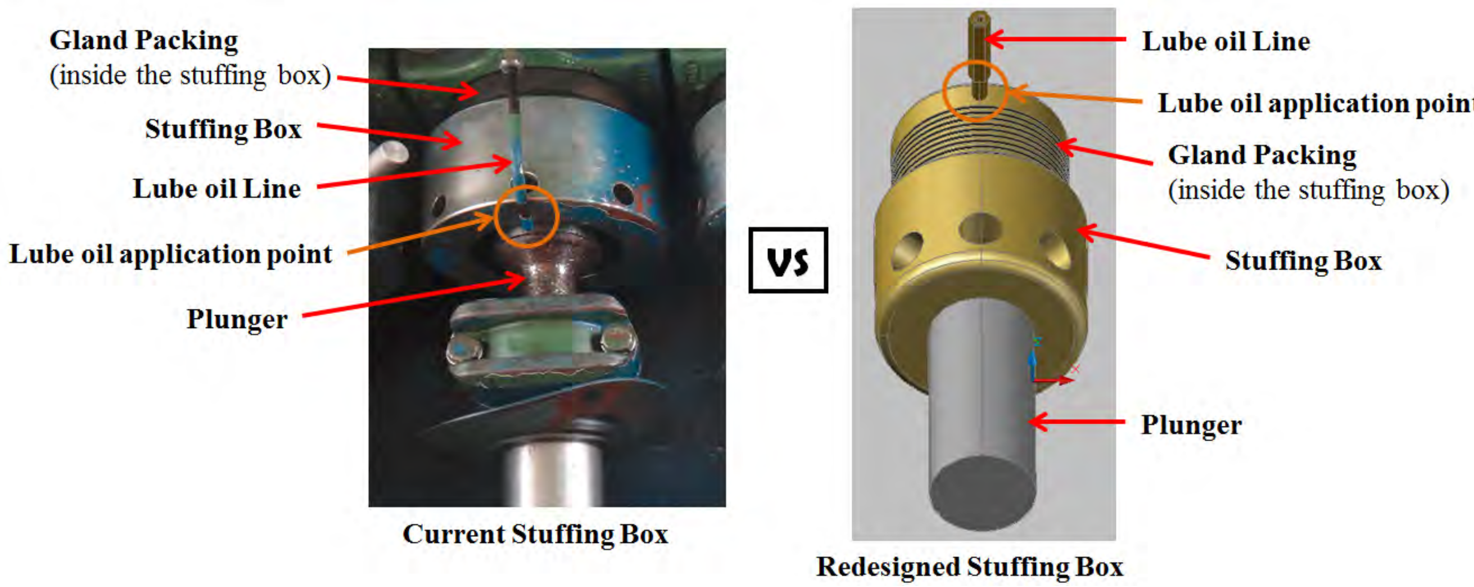

Figure 7: Current stuffing box versus redesigned stuffing box

The maintenance element encompassed the development of a maintenance life plan for the SP. Reliability-centered maintenance (RCM) was deployed to formulate the maintenance life plan for the SP.

Conclusion

For any given equipment failure in an organization, there are many routes to take to achieve remedial solutions. However, in order to maintain competitive advantage, the best route must be adopted. The best route is the option that would prevent failure recurrence at minimal cost.

In the case of the SP, the identified implementation routes were adopting a duty/standby configuration, retrofitting and a new purchase. By subjecting these implementation routes to multiple criteria, the retrofitting option emerged as the best route. Thus, system modification was undertaken on the SP. The SP's system modification program was theoretically evaluated to have a potential of increasing the availability of the condensate service system by 26.7 percent and yielding a capital expenditure (CAPEX) savings of about $140,000 to $330,000. Such an increase in availability will minimize the lifecycle cost of the SP.

Furthermore, all change initiatives for equipment and/or processes must be governed by a MOC to ensure risks and/or hazards are not inadvertently introduced or increased by the change initiative. It is evident that if the process change was steered by MOC, recurring/imminent problems with the SP would have been averted earlier. Hence, no significant cost implications would have been sustained.

"The best route is the option that would prevent failure recurrence at minimal cost."

Acknowledgment

The work presented in this article is an excerpt from a "Reliability Engineering and Asset Management (REAM)" Master of Science dissertation from the University of Manchester, England.

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