

# ROTATING EQUIPMENT PUMP RELIABILITY UPGRADING PROJECT

by

**Ed Ringstead**

**Project Manager**

**Shell U.K. Limited**

**Stanlow Manufacturing Complex**

**Ellesmere Port, Wirral Cheshire**

**United Kingdom**



*Edward Ringstead is a Graduate Mechanical Engineer employed by Shell UK Limited at their Stanlow Refinery for the past 23 years. Mr. Ringstead is experienced in maintenance, shutdowns, and major projects. Until recently, he was Chemicals Engineering Manager responsible for coordination of engineering activities across all of the Chemical Production Units at Stanlow, including the unit where the project illustrated in this paper was carried out.*

*Mr. Ringstead is now Project Manager for the construction of a new unit within the Additives and Intermediates Complex.*

## ABSTRACT

In 1988, a general performance assessment was undertaken at Shell UK's Stanlow Manufacturing Complex to review its competitive position in the market place. The review concluded there was a high level of maintenance expenditure and associated equipment downtime. This, coupled with the introduction of recent UK legislation relating to the Control of Substances Hazardous to Health (COSHH), required a rethink in reliability methodology. To that end, a reliability drive was directed for all production units at Stanlow to improve plant availability and funds were made available for projects with an identifiable payback.

The recent appointment of the author to one of Stanlow's chemical production units coincided with the reliability drive. The impact of that initiative is presented.

## BACKGROUND

An initial review of maintenance trends highlighted that 30 percent of the £1.5m Production Unit maintenance budget was being expended on rotating equipment. Typically, this expenditure was in the replacement of mechanical seals, bearings, and general overhauls based on an inventory of 300 pumps. The Production Unit had a very poor reliability record, and there was a wish to improve the external image of the department, increase plant availability, and improve profitability. This was achieved through an investigation of the root cause of the problems with rotating equipment, leading to investment in new technology and people skills. The resulting reliability drive was unique in the managerial approach and became a trend setter for other units at Stanlow.

This particular production unit had six plants with their own unique environmental problems and contained many process streams of a hazardous nature (Figure 1). Process conditions were typically 150 to 300 lb systems operating at temperatures from ambient to 180°C and containing solids in suspension in numerous cases. There were some limited high pressure applications operat-

ing at 30 barg on U3000. Pump types were typically seven to fifteen kW horizontally mounted with overhung impellers, more recent units, such as U1500, were vertically inline close coupled of similar power range.

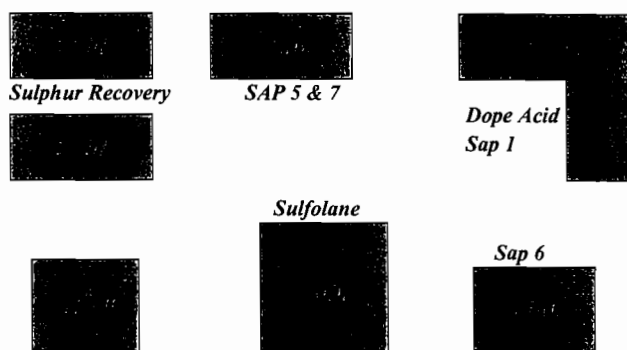


Figure 1. Production Unit Layout.

## INVESTIGATION

Preliminary observations indicated that a large number of pump seal failures had wear characteristics consistent with angular misalignment of the stationary seat and/or significant shaft deflections in the seal area. Such patterns are commonly associated with the following defects:

- Pump/motor misalignment
- Insufficient shaft rigidity
- Cavitation/vibration
- Operational factors

Subsequent investigations revealed that at least two of the above conditions existed in many of the pumps under review.

### Alignment

Although laser alignment equipment was available at the refinery, there was an inconsistent approach to the application of this technology. Various alignment systems were employed dependent upon the operating department, typically oil units (cat crackers, platformers, etc.) used laser equipment where the equipment size was large and significantly critical to plant availability. However, within chemical production units, i.e., additives, alcohols and resins etc., rotating elements were much smaller in horsepower and had simple rubber couplings that historically were aligned to less rigorous standards and operated on batch processes. Consequently, craftsmen on chemical production units were not fully conversant with laser alignment techniques. This theory was put to the test by field monitoring 170 chemical pumps using a contract

company to check alignment in situ. The results dramatically emphasized the acute alignment problem, as *all 170 pumps checked were outside tolerance.*

This problem was symptomatic of inadequate training of craftsmen in the use of laser alignment equipment and emphasized inconsistency of maintenance standards across the site. The alignment audit did provide a spin off as it was used in one-to-one training for craftsmen who readily benefited from the "hands on" approach.

#### Shaft Rigidity

A significant proportion of the department's pump inventory were horizontal single stage overhung impellers which had relatively slender shafts, typically 27 mm diameter, with 180 mm overhang.

A simplistic measure of shaft deflection, as seen in Figure 2, is a ratio of overhang to shaft diameter, i.e.,  $L^3/D^4$  ratio. Evaluation of the pump shaft population indicated at least 40 percent were in excess of the factor 300, while the recommended maximum factor is 75. Consequently, this inherent shaft flexing problem would lead to premature bearing and seal failures.

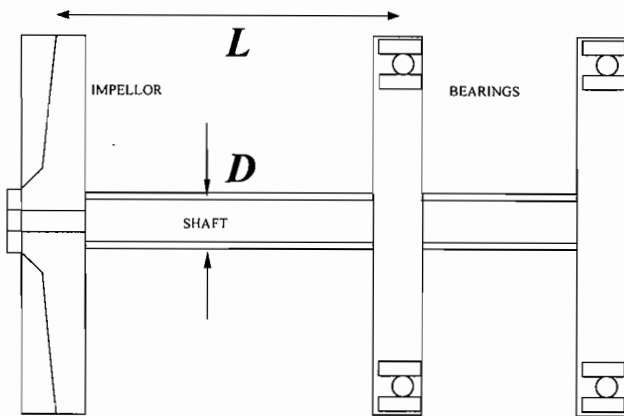


Figure 2. Standard Bearing Type.

#### Vibration Signature

Several causes of excessive vibration were identified during the investigation and were attributed to the following reasons:

- Alignment
- Equipment age
- Defective supporting
- Rotor balancing

#### Alignment

Vibration surveys indicated levels were generally in excess of the recommended 3.0 mm/sec, typically in the order of 5.0 to 8.0 mm/sec for those pumps surveyed. This was attributed to the poor alignment technology and maintenance acceptance standards.

#### Equipment Age

Some of the equipment was of such an age that the excessive vibration levels were accredited to looseness within the pump casing, on registers due to frequent pump overhauls, and the inevitable wear on parts. Rectification of this problem was normally accomplished by machining bearing housings to accept wearing.

#### Defective Supporting

Surveys of pump bed plates and pipe supports indicated vibration levels could be reduced with remedial work to rectify corrosion and provision of adequate pipe support bracing, which reduced nozzle loading.

#### Rotor Balancing

It was noted that balancing of rotating elements was standard practice within the "centralized maintenance workshop." However, within the production unit's own zone workshop, where the majority of pump overhauls were carried out, no balancing facilities existed. This led to high vibration levels being experienced on recently overhauled pumps by production unit craftsmen who did not apply a balancing procedure.

#### Operational Factors

Three factors specific to this Production Unit were found to be contributing to the continuing excessive failure rate:

- Condition monitoring
- Process criticality
- Failure reporting

#### Condition Monitoring

The refinery operated a vibration condition monitoring service for all production units across the site and relied on local knowledge to assess pump criticality. Evaluation of the 30 pumps that were subjected to periodic vibration monitoring across the department revealed that the equipment being monitored was not aligned with process criticality.

Localized condition monitoring using simple hand vibration meters was practiced infrequently by craftsmen within the department, who, although having access to the equipment, did not fully appreciate the significance of this technique.

Because of the acute alignment problem, it was necessary to train all craftsmen in basic awareness of vibration monitoring techniques and familiarize them with the audit capabilities of the monitoring tool. Once people realized an instrument was not a black box, but could check if alignment standards were being achieved, laser technology was accepted.

#### Process Criticality

Maintenance supervision had established a perception of equipment criticality based on supervision's "hassle factor," i.e., the frequency of which equipment appeared in the work shops. While this readily targeted "bad actors" it did not address production criticality for key equipment. It was only when a process flow diagram review of all units highlighted equipment criticality, that an effective vibration condition monitoring program could be implemented.

#### Failure Reporting

A significant number of manhours was expended in repairing equipment failures. This was due to the method of failure reporting, i.e., operators would report via a computer job card system that a pump was noisy or leaking—typically the latter. This inevitably led to an unplanned maintenance outage for the pump as the fault had been detected at a stage at which the seal was leaking and required immediate attention. This resulted in fire fighting maintenance involving urgent requests to stores for spare parts, progress chasing with vendors for unavailable spares and overtime working to get the equipment back online (Figure 3).

The introduction of the Reliability Team, who condition monitored critical equipment (by vibration monitoring) on a planned

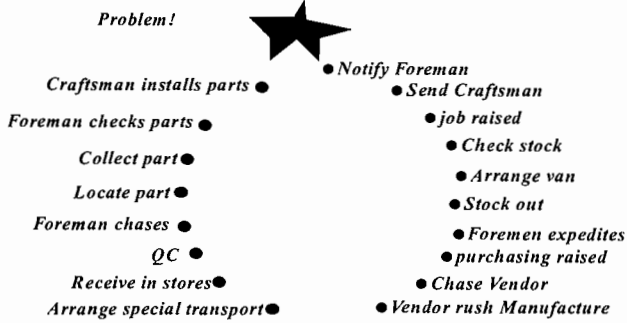


Figure 3. Firefighting.

basis, flagged up defects at an early stage and resulted in a reduction in unplanned downtime.

**MECHANICAL SEALS**

*Seal Distribution*

The existing mechanical seal distribution (Figure 4) across the department consisted of approximately 200 wedge type multi-spring pusher seals and 100 edge welded metal bellow seals, with a small number of single spring pusher seals. The metal bellow seals had been introduced with the recent addition in 1988 of a new operating unit. Previous maintenance supervision had also converted troublesome pusher seals with edge welded metal bellows.

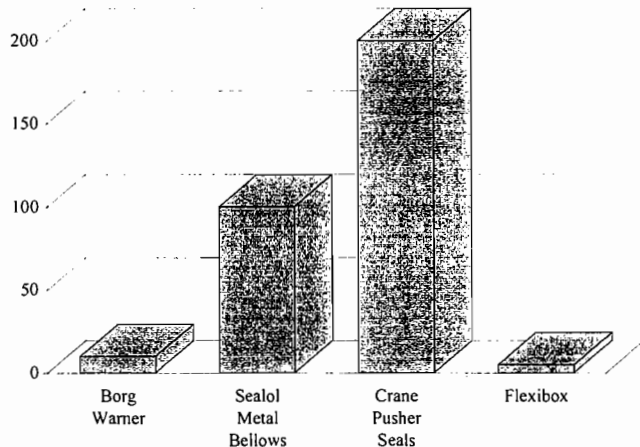


Figure 4. Mechanical Seal Distribution.

*Seal Failures*

Analysis of seal failure rates across the production unit highlighted approximately 25 percent higher failure rate within the pusher seal population to that of a similar plant that had exclusively metal bellows fitted. Both plants were particularly susceptible to solids ingress which may have caused the extended life expectancy of the bellows seals over that of the pusher seals.

*Seal Inventory*

An analysis of the seals population, shown in Figure 5, revealed a wide variety of design, size, material, and seat styles in the pusher type distribution, while the metal bellows population had a very small range of configurations. The only variation in the bellows seals was the use of silicon carbide as the rotating face in abrasive applications.

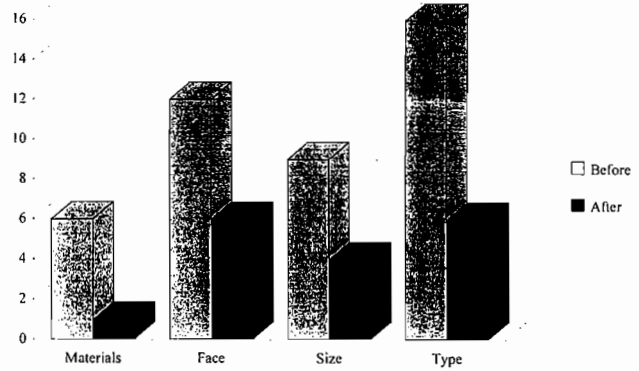


Figure 5. Seal Inventory Complexity.

A consequence of the large number of seal variations and the fact that seal spares were held at individual component level, was the very high stock levels required (882 individual items).

*Seal Modifications*

The age of equipment and lack of information had impacted on the maintenance staff in previous years, which resulted in non-standard seal configurations being concocted in efforts to keep the units running. This simply compounded an already confused craft force and spare parts situation and brought into question the credibility of even the sparse technical data available.

*Causes of Failure*

Between January 1988 and April 1989, 259 seal failures occurred across the department. The Central Refinery Rotating Group had been monitoring seal failures and carried out a detailed survey on this specific department and had examined 57 seal failures as part of a refinery-wide reliability survey. To elaborate a little on these failure modes the following comments attempt to clarify some of the more significant failures. Of all of the failures an underlying fact was that 80 percent were associated with people problems (Figure 6).

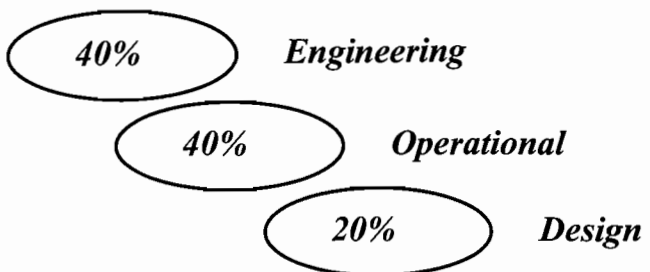


Figure 6. Causes of Failure.

*Abrasives*

Although solids are present in process streams in the form of carriers or catalyst, a by-product, called polysulfones, could be formed if the process strays outside of operating tolerance. This by-product, a crumbly plastic substance which clogs pusher seal springs cascaded through pump systems and resulted in successive seal failures.

*Misalignment*

It was not possible to segregate the various causes of failure due to misalignment as evidence was generally destroyed on disassem-

bly. However, the pump to motor misalignment and high  $L^3/D^4$  ratios were probably significant. In addition, many of the seals were fitted with clamped "T" section seats on PTFE gaskets. Measurements of some gaskets revealed lack of parallelism due to unequal tightening of gland bolts.

#### *Hang Up*

Many of the process liquids handled are either solutions, giving rise to atmospheric side deposits, or decompose in contact with the atmosphere that coats the shaft and inhibits the flexibility of dynamic sealing components.

#### *Bearing Failures*

Lubrication policy for rotating equipment in general has moved away from greased systems to oil filled reservoirs, with a limited use of oil mist systems installed predominantly on "oils" type production units. In this case, the lubrication regime was limited to conventional oil filled reservoirs using roller type bearings.

Bearing lubrication within the refinery is currently the responsibility of operations personnel. Historically however, this task was done by maintenance staff. Because of this transfer of responsibility, an inconsistent and erratic lubrication regime existed. Compounding this problem was the frequent use of high pressure water jetting due to blocked process lines that exposed bearing housings to a high probability of water contamination. There was certainly evidence of bearing failures during the survey which supported the questionable lubrication regime. The extent of poor lubrication would only emerge as a latent defect that was detected much later in the project (see POSTSCRIPT NOTES).

#### *Fitting*

Technical information available on the production unit was sparse, due to the age of equipment and various relocations of office data, and resulted in a lack of seal arrangement drawings. This, compounded with a wide seal spares inventory, led to confusion among the craft force on correct fitting dimensions.

Inconsistencies in fitting practice varied from compressing the same seal between unacceptable tolerances of 1.0 mm and 4.0 mm. Another common practice was to fit the seal in the same position on the shaft as indicated by the reference grub screw mark from the previously removed mechanical seal, both methods being inadequate.

The skill profile of the craftsman was a result of recent multidiscipline initiatives, which required ex-riggers, pipefitters, and fabricators to be expert in mechanical seals installation. This was sound in principle, although training regimes fell short of the desired maintenance requirements expected from traditionally time served mechanical fitters.

### RELIABILITY PROJECT

To address the foregoing issues and specifically troubleshoot "bad actors," i.e., repetitive failure, a dedicated Rotating Equipment Reliability Team was established headed by the author and supported by an experienced Rotating Equipment Supervisor. The group's aim was to identify equipment criticality and investigate specific "bad actors" and implement their solutions in the field, with the objective of reducing maintenance cost and improving plant up time.

The creation of a reliability team and the focus on rotating equipment enabled an indepth evaluation of the problems previously described and allowed time to formulate a maintenance strategy to rectify the situation. To this end, a project was developed with the following objectives:

- improve pump reliability
- reduce seal failures

- reduce seal inventory
- eliminate fire-fighting
- train craftsmen
- reduce maintenance costs

This program would afford an opportunity to standardize seal construction materials throughout the production units, which would bring benefits to both seal life expectancy and inventory part holdings.

The package of improvements necessary to address the above problems was to retrofit 144 mechanical seals from pusher type to metal bellows at a cost of £50,000. The justification for the capital expenditure was a reduction in spare parts inventory and a commitment/guarantee on seal failure rates based over a five year period.

The project strategy was based on the already proven superior reliability of edge-welded metal bellows, particularly in process streams containing solids. This involved a commercial evaluation with several seal manufacturers, which resulted in a partnership arrangement.

#### *Seal Upgrading Contract*

##### *Contract Goals*

A unique element of the seal upgrading contract was the commitment by both the client and the vendor to solve repetitive seal failures and establish longterm failure targets to improve plant availability.

The project goal was to reduce the annual 245 seal failures to 100 in year one of the contract, reducing over the next four years down to 75 per annum.

Deviation from these target norms would result in a free refurbishment or replacement of the offending seal subject to the qualification that the reason for the failure was not attributable to the client.

##### *Contract Qualifications*

The onerous conditions of the contract should the seal failure rate be exceeded were obviously qualified by the vendor to ensure certain standards were maintained during the retrofit program. Namely, these were that each seal conversion would be installed on a correctly overhauled pump to manufacturer's tolerances and dynamically balanced by the Central Workshop, prior to installation on the plant. The pump would be correctly aligned using laser optical equipment. The vibration signature of the equipment would not exceed 3.0 mm/sec. Any bed plate or pipe stresses that impacted on vibration levels was to be rectified by the client. All seal conversions would be supervised by the vendor's personnel.

Finally, any subsequent seal failure would be sent to the vendor for analysis and, should the failure be deemed to be client oriented, i.e., quenches switched off or dry running, etc., failures would not be reimbursed by the vendor.

The contract was, therefore, a true partnership with stringent requirements on both parties to ensure correct measures were taken.

##### *Secondary Objectives*

In addition to the financial benefits the project would address, there were a number of secondary objectives associated with people and technical data.

##### *Craft Skill Upgrading*

A project requirement was that each craftsman be trained on a one-to-one basis in the use of laser alignment. The vendor was commissioned to give detailed instruction in correct seal fitting techniques. Combined maintenance staff and operational person-

nel training sessions were required to emphasis the need for the correct operation of seal auxiliary systems such as flush systems seal quenches, etc.

*Technical Improvements*

The following technical requirements were implemented on the project:

A complete seal standardization program was implemented with the objective of reducing the seal inventory to the smallest material combinations.

The reduction of the number of seal sizes to an absolute minimum target of four sizes to cover at least 90 percent of pump distribution.

Troubleshooting repetitive failures in collaboration with the Refinery Rotating Equipment Group.

Production of a rotating equipment data book detailing process conditions, pumping characteristics, shaft sizes, pertinent to the detailed engineering package. This would contain seal installation data, part number recognition charts, troubleshooting tips, and seal pressure/temperature limits.

A wall chart containing detailed dimensional drawings of all seals supplied and installation information would also be required to provide instant workshop access to seal detail.

The vendor was required to undertake preparatory work to define pump types, sizes, and operating conditions. This proved to be an additional benefit in updating pump records and providing a high degree of project control.

*Seal Standardization*

It was determined that the metal bellows seal, with Carpenter 20 Cb3 metallurgy, was suitable for the majority of duties. The rotating face material could be either carbon or silicon carbide, dependent on abrasive content of the pump and complete standardization on one stationary seat style in silicon carbide was possible. With such a high degree of standardization a large reduction in inventory could be expected.

In fact, it was calculated that the number of inventory items could be reduced from 880 to 40 and still retain the required spares cover.

**IMPLEMENTATION**

The first pump overhauls and seal conversions under the project began in May 1990 and were completed in August 1992. A phased program was undertaken commencing with a process unit which was strategically critical to the business portfolio, and which was inherently more unreliable than the remaining units.

During the course of the project, a highly experienced pump/seal specialist was employed on a short term contract to ensure the vendor's installation requirements were implemented.

See the POSTSCRIPT NOTES for the further developments following completion of the seal rationalization program.

**RESULTS**

Following the successful retrofit program, results are emerging from the initial conversion which are very encouraging.

*Seal Failure Rates*

Seal failure rates are now at their lowest point ever, with only 52 failures of the converted seals since May 1990, an annualized rate of less than 23 failures a year—less than 10 percent of the previously experienced failure (Figure 7).

*Pump Maintenance*

Pump maintenance costs have fallen steadily over the course of the project, from £515,000 in 1990, £397,000 in 1991 to £365,000 in 1992 (Figures 8 and 9).

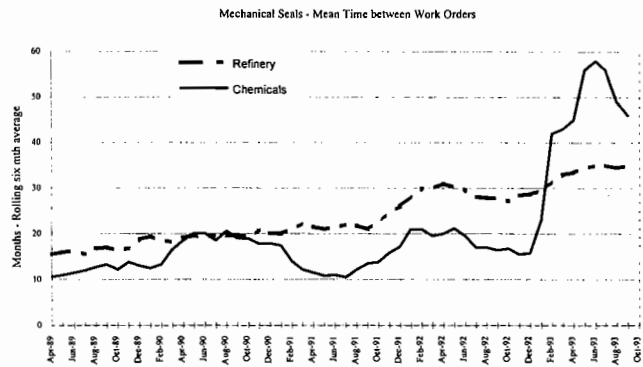


Figure 7. Mechanical Seals—Mean Time between Work Orders.

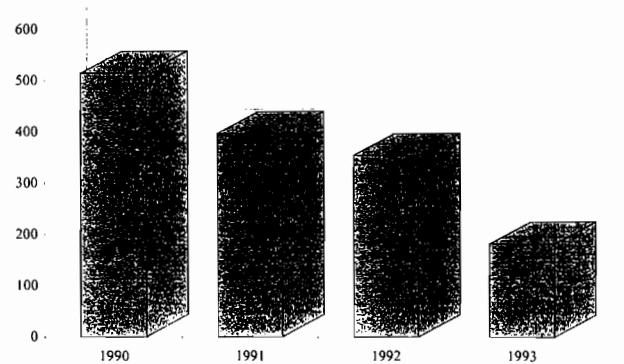


Figure 8. Pump Maintenance Costs (£k).

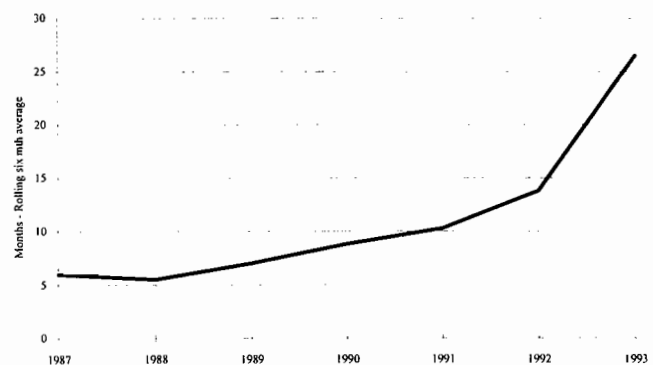


Figure 9. Rotating Equipment—Mean Time between Work Orders.

*Extended Production Runs*

Significantly, the largest of the three units involved achieved record production in 1991, as a direct result of the much improved pump reliability and personnel awareness.

**CONCLUSIONS**

*Equipment Reliability*

Equipment reliability on old process plants can be improved provided focus is placed on good basic maintenance practice, e.g., overhauling equipment to manufacturers' standards, balancing rotating elements, installation using laser alignment equipment, good lubrication regime and maintaining vibration signatures within 3.0 mm/sec.

*Craft Training*

Many of the reliability issues centered around people problems. Craftsmen/operators were either not following standard procedures, or not having sufficient training in the technologies required to meet acceptable standards. Focusing on people rather than hardware can have greater pay-back than capital investment projects. Training craftsmen, hands on, one-to-one, reduces fear of failure and is retained longer than classroom lectures.

*Troubleshooting*

Normal maintenance organizations do not have time to troubleshoot repetitive problems and a specific team assigned to tackle reliability issues is essential if a step change is required in plant availability.

*Maintenance Budget*

Significant reductions in maintenance expenditure can be achieved by assessing process equipment criticality and focusing on essential maintenance activities, and monitoring the quality of overhaul work performed by the craftsmen by vibration monitoring.

*Improved Contracting*

A partnering contract with supply vendors can significantly reduce parts inventories and eliminate repetitive failures provided

both parties are committed to reducing equipment downtime and improving equipment reliability.

**POSTSCRIPT NOTE**

Since the completion of the seal rationalization program, the mean time between failures has been significantly extended, which has highlighted a previously unnoticed latent defect of bearing failure, due to poor lubrication.

Bearing failure became an issue as seal life was extended and bearing failures which occurred on a more prolonged life cycle emerged. The bearing failures have been discussed previously, but it was also noted following a luboil survey that only one pump out of 50 sampled had not been contaminated by product or ingress of water.

The survey found that the one noncontaminated pump was fitted with labyrinth seals on the bearing housing while the remaining 49, which were all contaminated, were fitted with rubber lip seals which have a running life of four months. This observation, albeit late in the conversion program, resulted in a second phase to install labyrinth seals on all rotating equipment across the Department. This program is nearing completion, with some 80 percent of the pump seal conversions completed and, to date, there have been no bearing failures on the department.