Proceedings of ENCIT 2010
Copyright © 2010 by ABCM
13th Brazilian Congress of Thermal Sciences and Engineering
December 05-10, 2010, Uberlandia, MG, Brazil

# Technical Assistance to the Manufacture, Construction and Assembly of Osorio-Canoas Oil Pipeline Flow Pumps

**First Author's Name, e-mail** Menezes Kellson Takenaka, kellson.telsan@petrobras.com.br
**Second Author's Name, e-mail** Junior, Joilson Rangel, joilson_jr@petrobras.com.br
**Third Author's Name, e-mail** Costa, José Coelho, jccoelho.telsan@petrobras.com.br
**Institution and address** Petroleo Brasileiro S/A – Petrobras, Rua Almirante Barroso 81, Downtown, Rio de Janeiro

**Abstract.** This paper reports the experiences acquired through the modifications and improvements implemented in the manufacture, construction and assembly of the oil flow centrifugal pumps of the Osorio-Canoas Oil Pipeline (OSCAN 22"), located in Rio Grande do Sul. The OSCAN 22" pumping capacity expansion was conceived aiming at meeting the Alberto Pasqualini Refinery (REFAP) processing increase project from 20,000 m³/day to 30,000 m³/day, besides changing the product profile from processed product to national high viscosity national oils. Due to this reason, a new pump park at the Almirante Soares Dutra Terminal (TEDUT) and a new intermediate pump station named Estação de Santo Antônio da Patrulha (ESPAT) have been erected. Thus, the oil received by a tanker and stored at TEDUT was now pumped to ESPAT and then to REFAP through a 97 km long and 22 inch diameter oil pipeline named OSCAN 22".*In order to get such oil flow done, 03 new main pumps have been installed at TEDUT, one of them being a stand-by one, and other 03 pumps at ESPAT, one of them being also a stand-by one. During the startup of TEDUT's pumps, high vibration levels were observed in the rotors and in the equipment structures. The values defined by the manufacturer for equipment alarm and shutdown were, respectively, 50.0 µm and 75.0 µm, measured on the pump rotors in the bearing region. However, the global vibration levels of the TEDUT's pumps reached 110.0 µm during the startup attended by the manufacturers.*

*The equipment warranty period started after that, and a detailed activity planning was drawn up with the purpose of keeping TEDUT running with the new pumps at the lowest possible operational risk and avoiding a production reduction at REFAP. Simultaneously, various actions were taken in order to identify the vibration sources and reduce its intensity to the lowest possible values. After equipment modifications, median vibration values at 15.0 µm were obtained.*

*The logistics adopted in this process and the activities carried out to eliminate the causes of the high pump vibrations prevented an approximately R$ 40 million loss for the COMPANY and ensured an expressive increase in the equipment operational continuity reliability.*

*Using the lessons learned in the manufacture, construction and assembly of the TEDUT pumps, the points to be worked at ESPAT were defined in order that the plant startup would not present the same problems. In addition, the same actions have been currently employed in another undertaking of the ENGINEERING sector, the OSVAT 30, and they will certainly continue to be employed in several future works*

***Keywords**:* Centrifugal Pump, *Vibration.*

## 1. INTRODUCTION

The Alberto Pasqualini Refinery (REFAP) production capacity expansion project through the Osório-Canoas Oil Pipeline (OSCAN 22), was divided into the modernization and pumping capacity increase of the Soares Dutra Terminal (TEDUT) and the creation of the Santo Antônio da Patrulha Station (ESPAT).

REFAP was initially supplied with oil by TEDUT's old 20,000 m³/h flow-limited transfer pumps. With TEDUT's modernization and capacity expansion, it would be possible to send directly to REFAP 24,000 m³/h oil average. This step of the project should be concluded within approx. 06 months before ESPAT operation startup. With TEDUT and ESPAT operating in series, the pumping capacity for the refinery would be expanded to 30,000 m³/h. This would meet the refinery's demand after its expansion.

Copyright © 2010 by ABCM

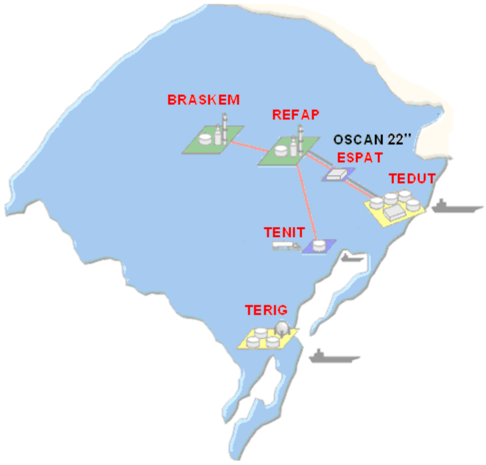


*Figure 1: REFAP Supply Logistics.*

## 2. PROJECT CHARACTERISTICS

The centrifugal pumps applied to the OSCAN 22" flow system are built according to BB1-type (Between Bearings) construction, as classified under the *American Petroleum Institute* (API) 610 – eighth edition *Centrifugal Pumps for Petroleum, Heavy Duty Chemical, and Gas Industry Services* [1] Standard. Although being of the same model when compared to ESPAT pumps, TEDUT's pumps have different rotor dimensions.

This equipment was designed by supplier and built to operate with diverse oil types, with densities ranging from 720.0 kg/m³ to 940.0 kg/m³ and viscosities ranging from 0.5 cP and 500.0 cP, according to REFAP production programming.

OSCAN 22" main pumps operate in series, at approximately 1950.0 m³/h flows for light oil and 1350.0 m³/m for heavy oil. The discharge pressure at TEDUT's pumps is 50,0 kgf/cm². After running 45 km through the oil pipeline, the product reaches ESPAT at 6.0 kgf/cm². At ESPAT, the oil is re-pumped to REFAP, and once more expelled through the pump discharge at 50.0 kgf/cm².

These pumps were the first equipment purchased by PETROBRAS for this service to operate with an impeller radial double-outlet design. This change was implemented by the manufacturer as an improvement in this centrifugal pump model building process.

ESPAT's concept of remote operation aided by a continuous monitoring system of the vibrations and temperatures on the equipment's bearings is another important characteristic of this design. The system's remote operation is carried out by the National Operational Control Center (*Centro Nacional de Controle Operacional* - CNCO), in Rio de Janeiro, without any local attendance, thus configuring a completely unattended operation. For this reason, the data supervision, control and acquisition system is extremely important to the equipment's operational availability.

## 3.0. DYNAMIC INSTABILITY CHARACTERIZATION

Since their startup, TEDUT's pumps have presented high vibration levels, reaching global values of up to 110.0 µm, whose amplitude varied according to the pumped oil density. The manufacturing standard [1] defines 30.0 µm as the maximum global vibration value obtained during the pump tests at the manufacturer's facilities as measured on the pump rotors in the bearing area. The values defined by the manufacturer for equipment alarm and shutdown were, respectively, 50.0 µm and 75.0 µm. Therefore, the operation of the equipment in field started in extreme operational status, with high risks of mechanical failure and, consequently, refinery supply shortage.

In equipment running with hydrodynamic bearings, which sustaining pressure is created by the relative displacement between the shaft and the oil film, monitoring becomes necessary through displacement sensors (proximeters). Proximeters are inductive sensors sensitive to the corresponding electromagnetic camp variation. For the correct identification of the shaft position in relation to the bearing and the reliable measurement of the shaft displacement values (radially measured), it is necessary to utilize 02 sensors assembled with a 90° spacing between them, as shown in Figures 2 and 3.

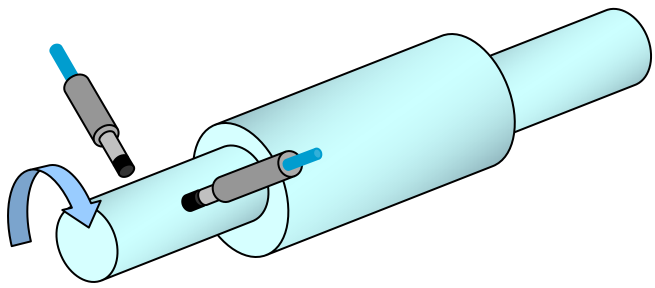

Figure 2: Sensors positioning schematic illustration

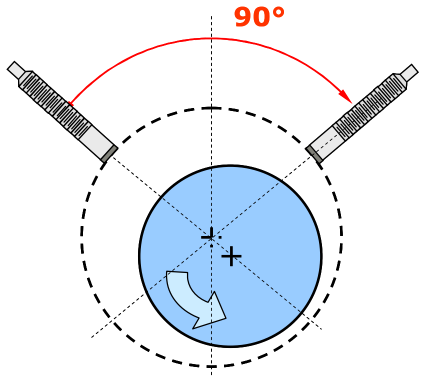


Figure 3: Proximeter assembly angle

Through the vibration analysis, obtained by the utilization of proximeters in this project, a great variation of the vibration amplitude with low frequencies excitations was verified, including the measurement in the time domain (temporal), confirming the values presented by the supervision. Such variation indicated bearing axis instability.

## 4.0 – PROBABLE CAUSES FOR THE DYNAMIC INSTABILITY

After the dynamic monitoring, the probable following causes were indicated:

- Fluid turbulent flow at the impeller’s inlet caused by the piping design configuration;
- Typical metal base frequency very close to the pump’s operational frequency;
- Impeller’s hydraulic unbalance;
- Rotor misalignment due to casing casting and/or machining deviations;
- Excessive bearing clearance.
-

## 5.0 – DIFFICULTIES FOUND

Among the difficulties found in the investigation process of the problem root cause, we can mention:

- TEDUT’s pumps already in field and operating in highly unfavorable dynamic conditions;
- ESPAT’s pumps already built, in plant-test phase and, originally manufactured in the same way as TEDUT’s pumps;
- Planning for intervention in pumps operating at TEDUT, depending on short low-demand periods in REFAP’s processing schedule;
- Interface with manufacturer;
- Intensive PETROBRAS supervision in the presence of the manufacturer is required which consumes great HH.

## 6.0 – LOGISTIC SCHEDULE

In face of the difficulties found, the following activities schedule was established:

- TEDUT’s pumps (6001-I, 6001-J and 6001-L) would return, one by one, to the manufacturer’s premises for re-work, without, however, interrupting pumping to REFAP. Thus, the terminal would start to operate during a determined period without a standby equipment;
- ESPAT’s pumps (7001-A, 7001-B and 7001-C) would be kept at the manufacturer’s premises for re-work;
- The pump delivery term should not alter the ESPAT’s work timeline;
- All the changes to be implemented in the equipment would depend on PRETROBRAS’ approval/knowledge;
- All the modifications carried out, transport, subcontracting, etc. should be performed without onus to PETROBRAS.
-

## 7.0 – PROPOSED ALTERNATIVES

With the in-plant equipment disassembly and PETROBRAS reasonable supervision, other failures were identified in the equipment that could be contributing to the high vibration levels under operation. Therefore, new guidelines were established to eliminate the problem:

- Replacement of the impellers for parts melted in ceramic molds;
- Verification of the impeller and rotating assembly’s dynamic balance;
- Superficial finish suitability (run out) in the vibration sensors’ operating region;
- Replacement of the bearings that presented excessive clearance;
- Modification of the forced-lubrication pump coupling sleeve;
- Verification of the melted casings’ manufacturing dimensional clearances and tolerances;
- In-Plant Mechanical Operation and Performance Testing, in plant, as per in-field pipeline layout.

## 8.0 –CRITICAL ANALYSIS OF PROPOSED ALTERNATIVES

### 8.1 Impeller replacement

The replacement of the impellers originally melted in sand mold for components melted in ceramic molds aimed at eliminating the maximum of dimensional deviations (of approximately 20%) in the impeller fluid exit areas. A greater dimensional uniformity in this region provides a better radial distribution of pressure and, consequently, a greater rotor hydraulic balance.

Figure 6: Impeller detail

### 8.2 – Rotating Assembly Balance

During the verification of the pump impellers' residual balance level according ISO 1940 [2], the execution procedure was found not to be a guarantee of satisfactory results repeatability. The impeller's fixing mode in the balancing machine, through a conic device, did not present enough centralization and hardness.

Another deviation observed was the non utilization of the wear rings during the individual balance process of the impellers. In addition, the bearing box deflector rings were not assembled during the complete rotating assembly balance either.

After the changes implemented by supplier in the device and in the balancing execution procedure, substantial improvement was achieved on the rotating assembly balancing repeatability and final values.

### 8.3 – Superficial finish suitability in the vibration sensors operating region

With the rotor disassembly, it was evidenced that the manufacturer has not carried out the effective control of the shaft's run-out in the proximeter operating region (Figure 7).

According to the manufacturing standard applied to the specification for combined electric and mechanical run-out, it shall not exceed 25% of the maximum allowed peak-to-peak vibration amplitude, or 12 µm, which happens to be the lowest.

The mechanical run-out reduction in the vibration sensor region was carried out through burnishing. After this operation, the values reached in all shafts were under 9.0 µm.

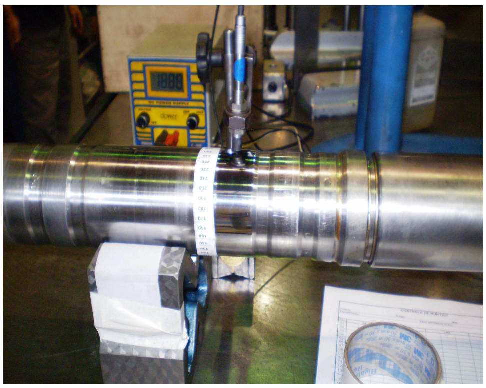

Figure 7: Shaft run-out verification

**8.4 – Sliding-bearing clearance suitability**

No measurement record of the assembly clearances of the original bearings' bushings was found. After their dimensional inspection, it was observed the use of bearings with diameters close to or superior to the design maximum values.

Bearing bushings were changed and further dimensional control was carried out by a SEQUI (CD-N2) qualified inspector, in order to guarantee the assembly tolerances.

The sliding bearings used are of four segments type, that is, they have four (04) lobules in the bearing perimeter in order to form an oil wedge. This building characteristic provides the material with high hardness and damping, when it works within the assembly allowed clearances.

**8.5 – Modification of the forced-lubrication pump coupling sleeve**

The forced-lubrication main pump coupling sleeve design (figures 08 and 09), manufacturing and assembly were changed with the purpose of eliminating the vibration induced to the oil transfer pump shaft in the bearing region on the opposite side to the coupling (LOA).

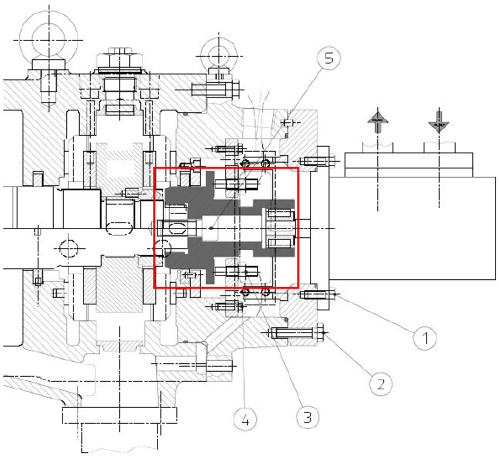


Figure 8: Forced-lubrication pump fixing sleeve detail

The main changes implemented in the coupling sleeve were the following:

- Sleeve fixation onto the main shaft, through 180° out-of-phase and round- profiled pins in order to mitigate the effects of possible  misalignments with the main pump shaft (figure 10);
- Alteration of the diameter of the bolt which fixes the sleeve onto the main shaft from M12 to M16, in order to ensure the 0.05mm maximum stipulated beat, and, consequently, the assembly repeatability (figure 10);
- Superficial sleeve hardness increase through nitriding, in order to eliminate possible distortion effects of the coupling sleeve during operation (figure 10);

Figure 9: Original sleeve

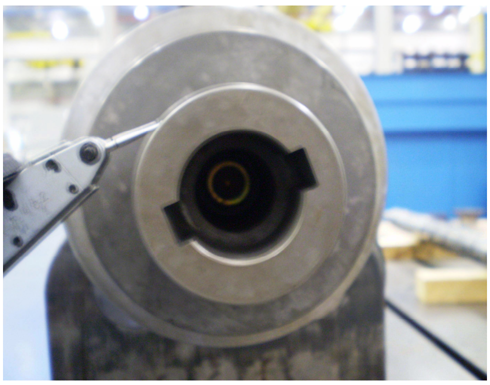

Figure 10: Modified sleeve

**8.6 – Verification of the melted casing manufacturing clearances and dimensional tolerances**

A dimensional inspection was carried out in all melted casings under ASTM A216 WCB [3]. Such three-dimensional measurements were carried out with the casings opened and closed aiming at verifying the clearances, flatness, perpendicularity, circularity and parallelism of the following regions:

- Bearing box setting face;
- Mechanical seal setting face;
- Stationary wear rings setting face.

Although no considerable wear was found that would cause discard of parts, the measurements carried out with closed casings proved to be more effective and reliable, therefore the manufacturer's procedure was recommended.

**8.7 – Mechanical Performance and Operation Testing on the testing bench**

After the implementation of all the changes and improvements, the pumps were assembled on the manufacturer's bench to be tested as to mechanical performance and operation. PETROBRAS requested that all the tests were carried out attempting to simulate as much as possible the in-field operational conditions. Therefore, the manufacturer should use the following equipment for the test:

- Pipelines of the same field diameter in order to simulate the flow speed influence;
- Field pipeline Lay out with a turn placed 01 meter away from the suction, in order to verify the turbulent flow influence, as per Figure 11;
- Forced-lubrication main pump assembled and pressurized in closed circuit, in order to simulate the dynamic efforts induced in the shaft end.

During tests, the following parameters were monitored:

- Bearing mechanical vibration;
- Shaft mechanical vibration;
- Bearing external temperature;
- Oil temperature;
- Noise level;
- Manometric height x flow;
- Efficiency x flow
- Consumed power x flow;
- NPSH x flow

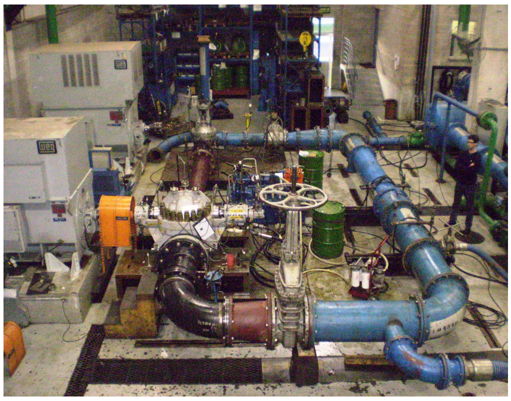

Figure 11: Layout for performance testing

Test showed that, after the implementation of all changes and improvements, the evaluated points presented pretty satisfactory results when compared to those recommended by the manufacturing standard [1].

**8.8 – Estação Santo Antônio de Paula (ESPAT) Commissioning**

While the modifications and improvements were being implemented in the TEDUT's stand-by pump and in the ESPAT's 03 pumps, REFAP kept being supplied by the 02 TEDUT's pumps in extreme vibration conditions. Due to this situation, some pumping units' components were damaged, such as sensors, transmitters, indicators, etc. The operational continuity of the 02 unit was only possible due to the possibility of immediate removal of these components from the idle facilities.

With the activities end of in-plant activities, the pumps were assembled and commissioned at the respective terminals. For the commissioning of the ESPAT (B-7001 A/B/C) pumps, a sequence of individual field tests was defined If each one of them presented satisfactory dynamic condition, the next step would be the test together with the TEDUT's pumps.

On December 02, 2009, the commissioning of the B-7001 B and C pumps was carried out, and both of them presented satisfactory mechanical results, with mechanical vibration values below 18 µm, with 50 µm being an alarm level. During these individual tests, the pumps operated at 1200 m³/h, close to the minimal flow and out of the equipment operation preferred region.

On December 03, 2009, the B-7001 A pump commissioning was carried out, individually, and, since it also presented satisfactory dynamic condition, with vibration levels below 16 µm, the next step was to test together with the TEDUT's pumps in order to reach the intended flow of 2000 m³/h.

As expected, the ESPAT's pumps working in series with the TEDUT's pumps at the design flow (1950 m³/h) presented an even better dynamic condition and vibration values below 12 µm. The temperature values are found constant and within the manufacturing standard [1] accepted limits throughout the whole commissioning.

**11.0 – LEARNED LESSONS**

The present document reports an atypical manufacturing supervision situation, since it is expected that the whole design, manufacturing and assembly process of the components comprising the pump be reasonably carried out and within the quality standards. As described in the document body, deviations occurred from the design stage, passing through the component manufacturing until lack of criteria in the pump assembly. In face of the occurrences observed, we suggest as follows:

- Reasonable periodic appraisals shall be carried out in the equipment manufacturing processes of companies registered at PETROBRAS Suppliers List, with the purpose of ensuring the compliance with the QSMS-related contract and normative requirements;
- Intermediate inspections of suppliers that present frequent quality problems in their final product shall be intensified;
- The application of sanctions to suppliers with reiterated high severity problems;
- Suppliers shall be requested to inform in advance of any modifications carried out in their products in order to allow for a previous evaluation of possible problems;
- Operational tests shall be carried out on equipment run with hydrodynamic bearings in the presence of the forced-lubrication pump assembled and pressurized in closed circuit. This item was validated as Learned Lesson at the ENGINEERING sector's SINAPSE to be included as a contract requirement of PETROBRAS.

**12.0 – CONCLUSIONS**

The technical appraisals and the logistic planning carried out in this specialized assistance increased the reliability and operational continuity of the units and avoided a high loss to the COMPANY.

If the new TEDUT's pumps were not kept in operation, it would require approx. 10 days to resume the old system's operation, which would reduce the refinery production in this period from 20,000 m³/day to 17,000 m³/day, with the gradual consumption of its inventory of approximately 200,000 m³. It would represent an invoicing fall to REFAP and TRANSPETRO, besides an additional cost of oil tanker's demurrage, which, together, would reach R$7.5 million. If we consider that the new TEDUT's pumps would have a 24,000 m³/day pumping capacity, the resumption of the old system would accordingly result in a 4,000 m³/day reduction in the expected oil flow capacity to REFAP. Further assuming that 180 days were required for the equipment removal and reinstallation after the implementation of all modifications and improvements, this would result in an invoicing fall of around R$32 million REFAP and TRANSPETRO.

The whole equipment is currently operating with vibration levels lower than 20 µm, and the manufacturer's initial recommendations as to equipment's alarm and shut down levels respectively equal to 50 µm and 75 µm were kept. These measures caused a significant increase in the equipment operational continuity and reliability.

These actions were only possible due to the integrated action of the ENGINEERING/SL/SEQUI, ENGINEERING/IETEG/IETR and TRANSPETRO/OLEO/OP/SUL sectors.

The lessons learned at TEDUT and ESPAT are being currently applied to the OSVAT 30 Project and were included in the SINAPSE and validated in order to enable the application in several other PETROBRAS future Undertakings.

**13.0 – BIBILIOGRAPHIC REFERENCES**

[1] Centrifugal Pumps for Petroleum, Heavy Duty Chemical, and Gas Industry Services - American Petroleum Institute Standard – 610 - eighth edition

[2] Mechanical Vibration – Balance Quality requirements for rotor in constant (rigid) state – ISO 1940 – 1:2003

[3] Industrial Pumps – 2nd edition Falco, Reinaldo de

[4] Equipamentos Mecânicos – Analise de Falhas e Solução de Problemas – Luiz Otavio Affonso

[5] Desempenho de Turbomáquinas no Campo – Guilherme Leibsohn Martins

**14.0 – RESPONSIBILITY NOTICE**

The authors are the only responsible for the printed material included in this paper.