Enhancement of LNG Facility Maintenance Methods

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Background

Tokyo Gas has been operating LNG receiving terminals for more than four decades since 1969. Through long years of working to improve operations and maintenance technologies, Tokyo Gas has boosted the reliability of many LNG facilities, extended facility life span, and achieved reductions in the manpower and costs required for facilities maintenance. For example, when the LNG receiving terminals first began operations, the interval of overhauls for LNG pumps, which are key equipment, was determined by time-based maintenance (TBM) based on operating hours or on conditions monitoring through checks for unusual noises conducted during patrols. Many years of maintenance clarified the important damage modes. The company has successfully increased the mean time between failures (MTBF) by about five times compared with the early 1980s, prior to the introduction of conditions monitoring systems, by considering new maintenance methods such as conditions-based maintenance (CBM) using acceleration sensors while positively pursuing technology development.

This paper reports on the efforts made by Tokyo Gas to improve the facilities maintenance technologies and operating methods, centered on LNG pumps.

Past LNG Pump Maintenance

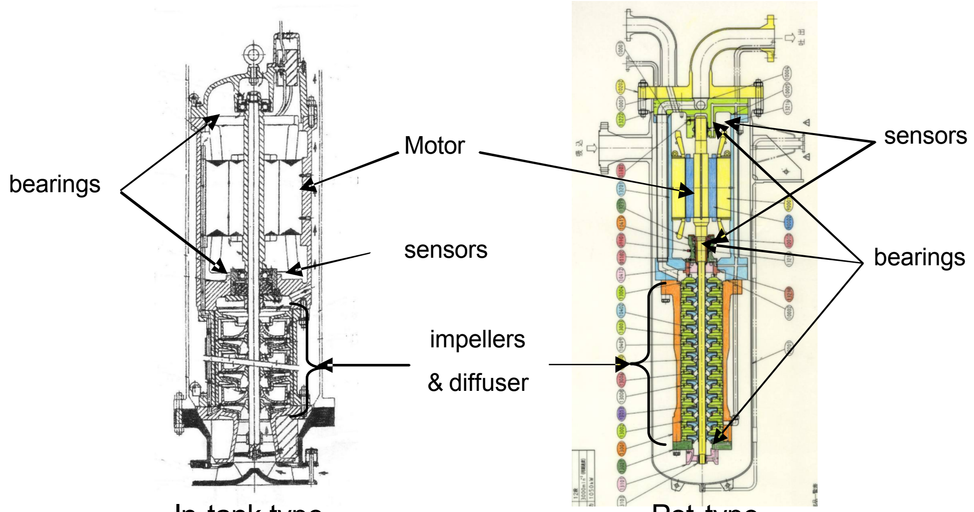
Tokyo Gas has three LNG receiving terminals in Negishi, Sodegaura, and Ohgishima. As shown in Table 2.1, a total of 126 LNG pumps, consisting of 75 in-tank pumps and 51 pot-type pumps, were in operation at these terminals in 2011.

Table 2.1 Number of LNG pumps at each Tokyo Gas LNG terminal (2011)

	Negishi	Sodegaura	Ohgishima	Total
In-tank type	21	41	13	75
Pot-type	10	32	9	51
Total	31	73	22	126

Figure 2.1 shows the structure of a typical LNG pump. LNG pumps are submerged-type pumps to prevent any leaks from the shaft seal, with the motor above and the impellers and diffusers below. The LNG is sucked up by the pump from the intake at the bottom and discharged from the top. The electric motor, which is heavy, impellers, and other rotors are

mounted on the shaft and the shaft is maintained using ball bearings. Vibration sensors are installed near the bearings to monitor the pump vibration.



In-tank type | Pot-type

Figure 2.1 LNG Pump Structure Schematic Diagram

Figure 2.2 presents the mean time between failures (MTBF) for the LNG pumps at the Sodegaura LNG Terminal, where Tokyo Gas has the largest number of LNG pumps installed.

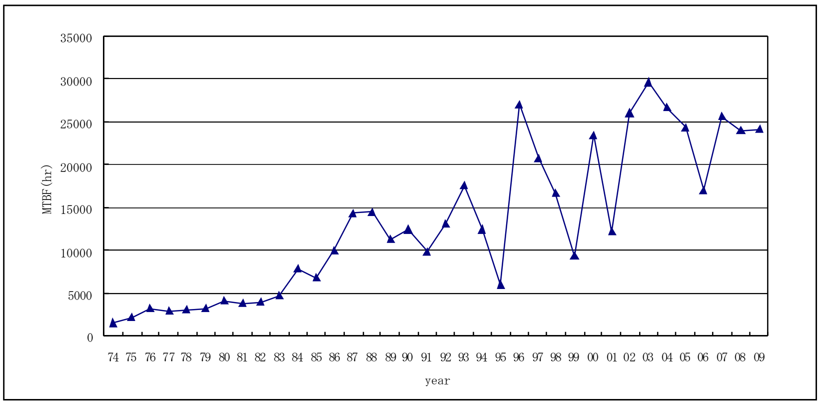


Figure 2.2 MTBF at the Sodegaura LNG Terminal (1974-2009)

When the LNG receiving terminals first began operations in the 1970s, the timing of overhauls for LNG pumps was determined by TBM or by CBM through checks for unusual noises during patrols, but the pumps only functioned stably for a few hundred hours before needing to be overhauled. From the perspectives of stable sendout of city gas and reduction of maintenance costs, Tokyo Gas has implemented all types of improvements to lengthen operating hours and extend the life span of the pumps.

Introduction of CBM for LNG Pumps

An LNG pump vibration monitoring system was introduced in the early 1980s to prolong overhaul intervals as long as the pump operating conditions remained good, and for early detection of unusual state to minimize equipment damage. Figure 3.1 is a schematic diagram of the vibration monitoring system.

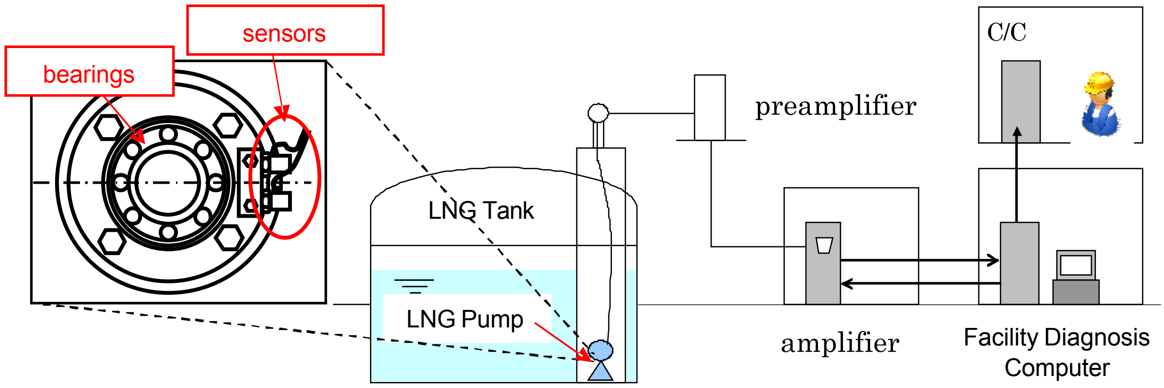


Figure 3.1 Vibration Monitoring System Schematic Diagram

Based on overhall maintenance results from the installation of ball bearing type LNG pumps, damage to the bearings under the motor mainly determined the overhall interval. Also, when the ball bearings were damaged, the Power Spectrum (PS) obtained from the acceleration sensors showed peaks in characteristic frequency bands.

Acceleration sensors were installed to monitor the conditions of the ball bearings as the primary target. The PS obtained was used to diagnose the conditions of the ball bearing type pumps. Also because the damage to the ball bearings was determined by the overhall intervals, abrasion of the bushings, wearings and others was not monitored. Rather, the monitoring was conducted using the power spectral overall level (O/A) as a reference index. Figure 3.2 presents sample vibration monitoring data.

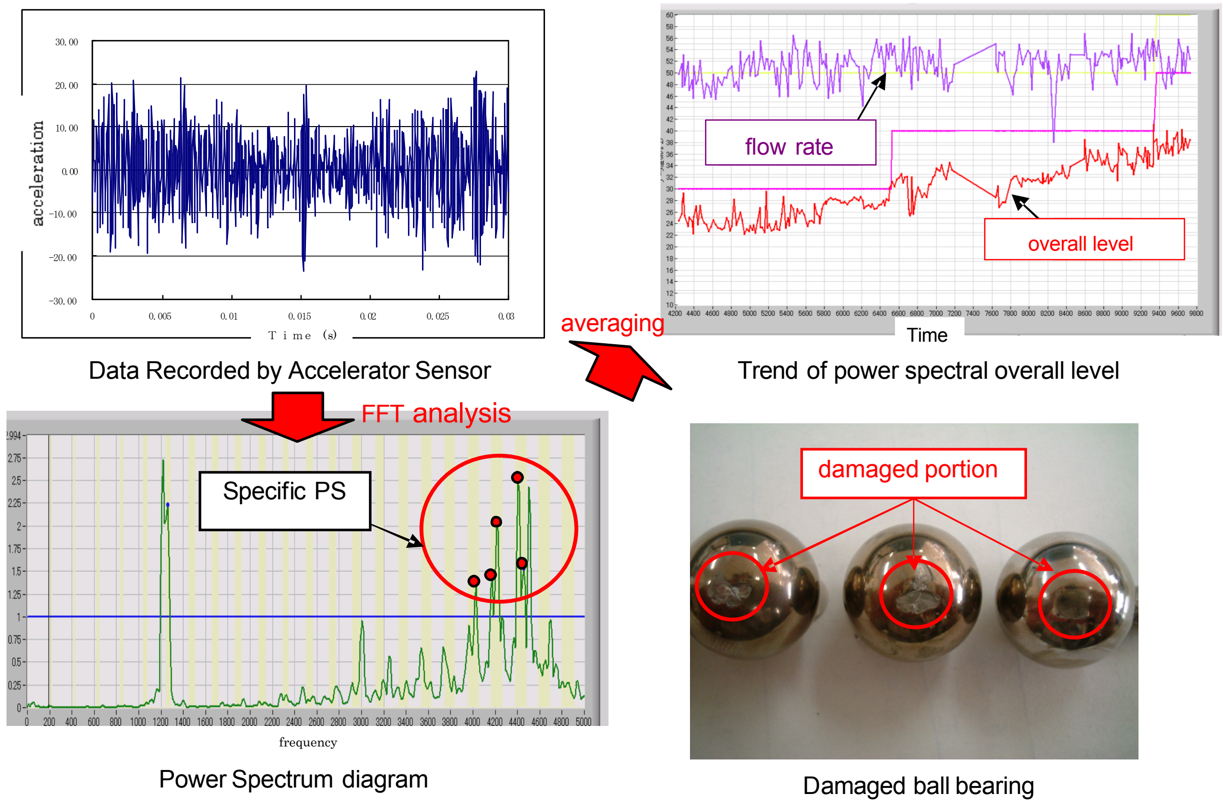


Figure 3.2 Sample Acceleration Data

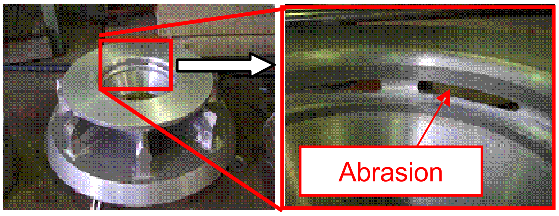
Emergence of New Damage and Countermeasures

1. Abrasion of Ball Bearing Type Pumps

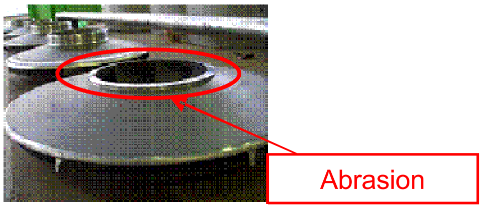
While the life span was successfully increased, there were cases of damage to LNG pumps that the vibration monitoring system had not found to have any unusual signs. Table 4.1 and Figure 4.1 present outlines of the pumps, operating conditions, and overhaul inspection findings for each example.

Table 4.1 Resultant of inspection for LNG pumps

		Example -1	Example -2
spec	year of manufacture	1974	1982
	quantity × head / stage	136 m^3/h×320m / 5 stages	273 m^3/h×330m / 3 stages
	MTBF	23,918 hr	47,341 hr
Inspection Resultant	impellers	exchange :1~ 3 stages repair :4~ 5 stages	exchange :1 stage repair :2~ 3 stages
	bearing	not particular	not particular



Suction manifold



Impeller

Figure 4.1 In-tank Pump Damage Example -1

The overhaul inspections confirmed considerable sliding abrasion of each pump. In Damage Example-1, the pump was replaced because the repair costs were equal to the replacement costs. In Damage Example-2, the impellers and other parts had to be replaced. The overhaul inspections confirmed the following points.

- The abrasion damage was increasingly severe toward the bottom of the pump (the inlet)
- None of the pumps showed any unusual abrasion of the bearings or bending of the shaft
- Looking at the PS characteristics during periods with a high O/A level, the PS value rises on the longer period on the 0-5,000Hz frequency band investigated for bearing damage

This type of unusual abrasion damage of ball bearing type pumps had never been reported before at Tokyo Gas. This was apparently because damage to ball bearings had been the main damage mode to ball bearing type pumps in the past, and the extension of the MTBF from implementing various countermeasures to ball bearing damage resulted in severe sliding abrasion that had not appeared in the past.

2. Improvement of LNG Pump Management Methods

These examinations of the damages to the ball bearing type pumps showed that it was difficult to monitor all the pump damage modes with the diagnosis methods used to date.

Based on the knowledge gained from the examinations, the diagnosis methods were improved to respond to the damage modes emerging in recent years. The main points of the improvements were as follows.

➢ Continuous Acceleration Sensor Monitoring

The acceleration sensor O/A level is continuously monitored to grasp the instantaneous increase in acceleration data that can be observed when slippage occurs and to prevent sudden damage from the intake of foreign matter.

➢ Analysis of Spectral Characteristics

The change in the power spectral waveform in the high frequency band (5,000Hz or higher) believed to occur when sliding abrasion occurs is used as a reference index to manage the sliding abrasion.

➢ Implementation of a Multiple Approach

Damage Example-1 and Damage Example-2 were both discovered because of declines in pump discharge flow. It seems that losses occurred from the increased sliding abrasion resulting in a decline in pump performance. So taking a multifaceted approach by supplementing the acceleration sensor data that is currently being monitored with operating load range, performance, pump efficiency, and other data from the discharge flow, pump motor current, and other indicators should facilitate the early detection of damage modes that are difficult to identify from acceleration data alone.

3. Development of Pump Barrel Function Recovery Technology in the Event of Damage to In-tank Pumps

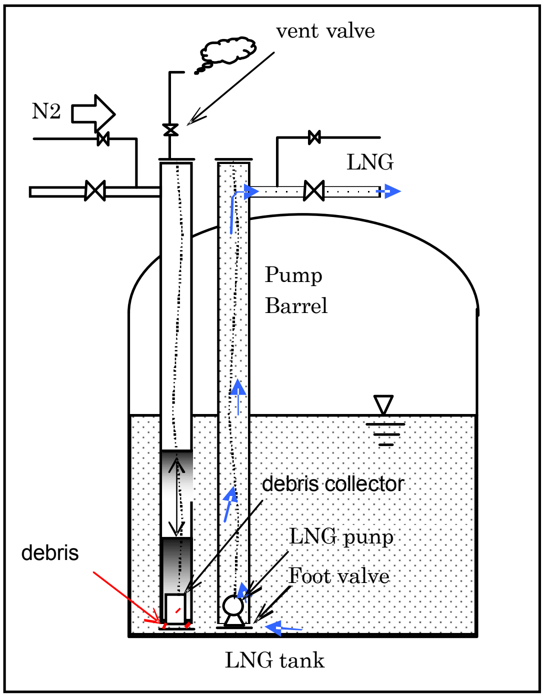
Even with rigorous pump maintenance using TBM, CBM, and other approaches, it is difficult to completely eliminate the possibility of large-scale damage from one cause or another. When major damage to in-tank pumps results in debris remaining in the pump barrel, there is a risk that such debris may be sucked up, in some cases resulting in a loss of pump barrel functionality.

Given the extremely high costs of opening tanks to restore pump barrel functionality, Tokyo Gas developed a simplified method collect to residue in the pump barrel. This technology may be summarized as follows.

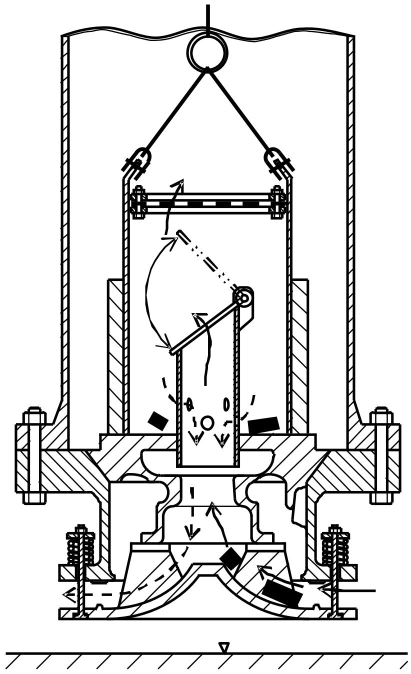
- ➢ The collector shown in Figure 4.5 was manufactured and installed inside the pump barrel.

- At first the LNG level in the pump barrel was pushed down using inert gas, then the pressure inside the barrel was lowered so that LNG abruptly flowed into the barrel.
- The debris was drawn into the collector from the fluid dynamics of the LNG flowing into the barrel, and then collected.

By implementing debris collection works using this technology, many pieces of debris from several millimeters to as much as 110mm in length that had been spread about the bottom of the pump barrel were successfully collected, restoring the pump barrel functionality.

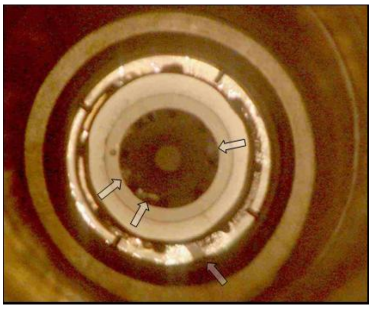


Systematic overview



Structure of debris collector

View of debris collector



Debris in Pump Barrel

Collected Debris

Figure 4.5 Pump Barrel Debris Collection Jig and Collected Debris

Additional Efforts to Extend Life Span

The LNG pump bearings are normal ball bearings. However, because LNG has low viscosity, the operating conditions are harsh with direct contact between ball and race. So the wear rate is faster than that of oil-lubricated ball bearings, and the ball bearing damage was determining when overhauls had to be implemented. Additionally, because of minute particles contained in the LNG, the bearing life spans were not uniform, giving the possibility of sudden breakdown.

To further increase life spans, Tokyo gas developed a hydrostatic slide bearing LNG pump together with the pump manufacturer. Hydrostatic slide bearings eliminate ball bearings, and they are designed to directly support the axis with the pump discharge fluid. So there is no abrasion because there is no contact between the axis and the bearings when the pump is operating, leaving very little risk of sudden breakdowns from minute particles or bearing deformation. Figure 5.11 presents a schematic diagram of the hydrostatic slide bearings . Because these bearings restrict axis vibration, they are attached above and below the motor, and at the very bottom of the pump. There are also supplementary ball bearings to support the pump weight when the pump is at rest and between the time the pump starts and when the hydrostatic slide bearings begin to function.

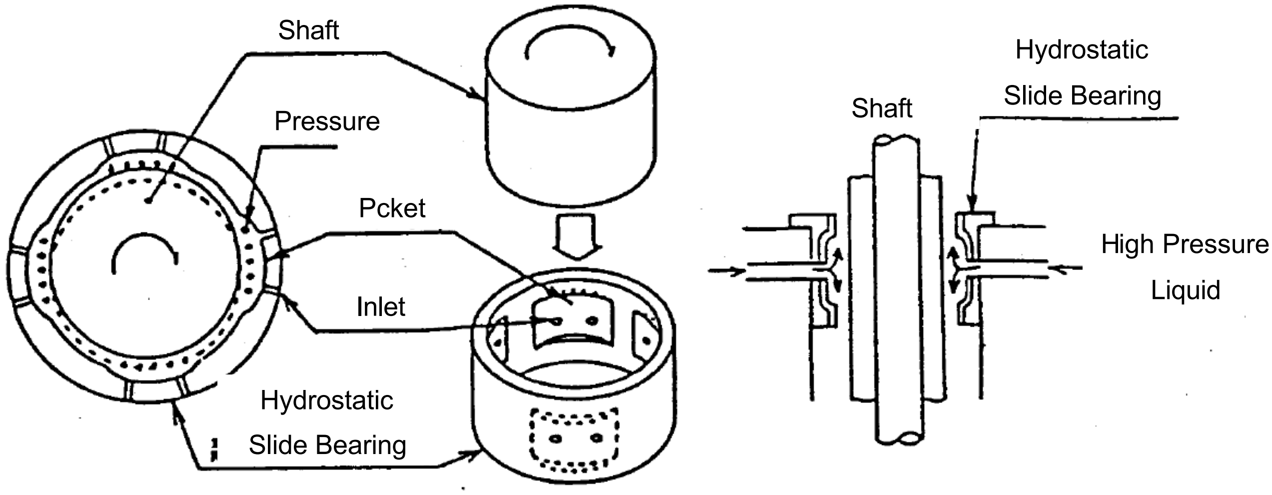


Figure 5.1 Hydrostatic Slide Bearings Schematic Diagram

In addition to hydrostatic slide bearings, the pump design also considered diverse structural aspects to limit bearing damage and sliding abrasion, including the following.

① Preventing axis thrust during operations using a thrust balance mechanism
② tReducing the number of stages using high head impellers, and shortening the length of the axis using a radial diffuser

By incorporating these types of design considerations, the overhaul intervals for the hydrostatic slide bearing type pumps were extended to approximately 40,000 hours, achieving a large expansion of life spans compared with ball bearing type pumps.

The monitoring of hydrostatic slide bearing type pumps targets the bearing abrasion damage using axis displacement sensors to monitor the axis swing during start up and at rest, and during operation (see Figure 5.2). Additionally, because the pump discharge fluid is not supplied to the hydrostatic slide bearings during start up and at rest, and there is abrasion to the sleeve from the axis swing, TBM is also used for the management based on the number of start ups.

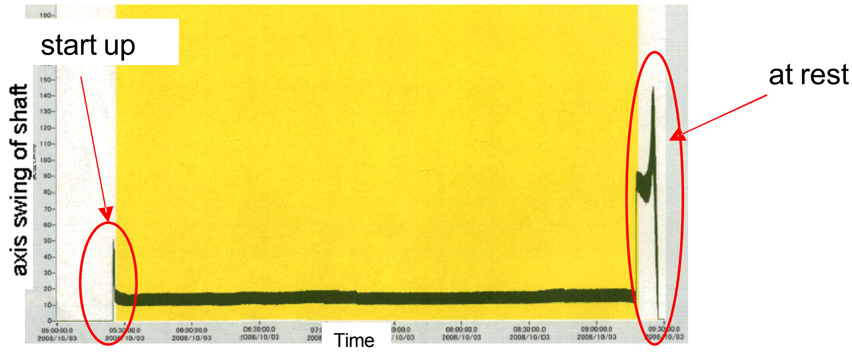


Figure 5.2 Hydrostatic slide Bearing Type Pump Axis Displacement Sample Monitoring Data

Conclusions

Based on its prior LNG facilities maintenance performance, Tokyo Gas has aimed at constructing an optimal maintenance system combining management based on operating hours with management based on operating conditions. The company has established a maintenance scheme that limits the operating risks from equipment downtime for optimal maintenance costs and stable supply, and will continue working to improve its LNG facilities management technologies.