TITLE: **Predictive Maintenance Benchmarking of LNG pumps**

AUTHORS :

- El Paso, (USA): Steve Heard
- Elengy, GdF SUEZ (F): Philippe Bouchy, Eric Gerard
- Enagas (E): Claudio Rodríguez, Ricardo Conde, Javier Perez, José A. Lana
- Fluxys LNG (B): Francis Van de Walle, Dirk Goeminne
- GNL Italia, (I): Manuela Lombardi, Edoardo Vestrini
- National Grid (UK): Ayo Ogunjumo
- Osaka Gas, (J): Masayuki Hirabayashi, Hiroshi Nishigami
- Sempra LNG (USA): Yovannis Mierez
- Tokyo Gas (J): Kuno Yasushi

Summary :

The work covered by this report is to focus on *benchmarking the predictive maintenance policy* for *cryogenic LNG pumps*, based on the measurement of vibration levels, on the LNG terminals of participating companies in this working group. Additionally, some information on BOG compressors was gathered. Non cryogenic equipment is outside the scope of work because it is assumed that most LNG Terminals have sufficient knowledge of this kind of equipment.

The main conclusions reached are:

- All working group companies have installed vibration measurement systems for performing predictive maintenance of cryogenic equipment. The systems can operate open or closed loop. The monitoring is mainly based on the vibration level of the LNG pump.
  Nowadays only one company uses *Condition Based Maintenance (CBM)* for LNG pump with submerged accelerometer, i.e., measurement done in cryogenic conditions, but it has no notion of the condition of the pumps because no mechanical maintenance of the pump has been performed up to now, since the installation of the CBM system.

VERSION / STATUS : **1.0 / FINAL**

SECURITY STATUS : **CONFIDENTIAL – within GIIGNL**

Document Information and Revision History

File Name	PMB1102-PMB_Report-V1-Final-20111220.doc
Document Number	PMB/11/02
Original Author(s)	J. A. Lana / J. Perez
Current Revision Author(s)	J. A. Lana / J. Perez

Version	Date	Author(s)	Revision Notes
0.1	4th May 2010	J. A. Lana J. Perez	First draft for comments of PMB Group Members.
0.2	7th June 2010	J.A. Lana J. Perez	Second draft for comments of PMB Group Members.
0.3	27th July 2010	J.A. Lana J. Perez	Final for comments of Technical Study Group members.
0.4	10th January 2011	J.A. Lana J. Perez	Final for last comments of Technical Study Group members.
1.0	20th December 2011	J.A. Lana J. Perez	Final version for GIIGNL web site

TABLE OF CONTENTS

Executive Summary

The work covered by this report is to focus on *benchmarking the predictive maintenance policy* for *cryogenic LNG pumps*, on the LNG terminals of participating companies in this working group, with the final objective of finding the optimum design or configuration of the sensor and attached equipment for getting a reliable measurement of the condition of the LNG pump. Additionally, some information on BOG compressors was gathered. Non cryogenic equipment are outside the scope of work because it is assumed that most LNG Terminals have sufficient knowledge of this kind of equipment.

In order to perform the work, the PMB group prepared several questionnaires that were answered by the participants. These questionnaires are the main result of the work because they reflect predictive maintenance practices of every single participant. The information gathered in the questionnaires was discussed and analysed in several meetings held by the working group.

The main conclusions reached are:

1.- All working group companies have installed measurement systems for doing predictive maintenance of cryogenic equipment. The system can work open loop (signal/alarm only) or closed loop (high signal shut down the pump automatically). The monitoring is mainly based on the vibration level of the LNG pump.

2.- Nowadays only one company is using CBM for LNG pump with submerged accelerometer, i.e., measurement done in cryogenic conditions, but it has no notion of the condition of the pumps because no mechanical maintenance has been performed up to now.

3.- Several companies are using CBM successfully for ex-tank LNG pump using non submerged accelerometer, i.e., not directly attached to the LNG pump.

4.- Several companies are relying on a MIXED maintenance strategy, i.e., the pumps are overhauled after a fixed number of running hours and a CBM system is installed to ensure that the pump is working properly up to the fixed period of time.

5.- The study has not revealed a clear reason why the CBM is not a reliable strategy for maintenance of LNG pumps for most of the group companies, although there are some tips: signal quality, level of alarm (to use wave form and vibration spectrum, not only fix value), position of sensor, number of sensors, …

    Anyway, the installation of vibration measurement systems on pumps in cryogenic service is becoming more common, but to solve the problems associated with interference in the signals should be a development issue, so more operating experience is required to gather data to demonstrate the true benefits of CBM on this equipment.

Some tips and general recommendations for improving the CBM are defined by the group, mainly based on the experience of Osaka Gas and Tokyo Gas, which seem to have the most stable signal and credible measurement for vibration. As well, these companies have offered to share their experience in CBM on an individual agreement basis with the interested companies.

After the last meeting held by the group, it was decided to finish the collaboration once the final report is approved, although maintaining contact and sharing some information by e-mail or through the TSG meetings. Anyway, depending on the results of some internal works currently in progress by different companies, the PMB group could start a new collaboration in the future.

1. Introduction

1.1 Background

To optimize maintenance management, in terms of minimizing cost and maximizing assets availability in the LNG industry, a shift of maintenance strategy from traditional *Original Equipment Manufacturer (OEM)* recommendations, based on periodical substitutions of parts, to a more efficient and modern strategy based on monitoring the machine and on its condition, is advised.

Predictive Maintenance is *Condition Based Maintenance* or *On Condition Maintenance*, based on the utilization of sensors/devices to check the state of the equipment prior to its failure, with the idea of extending the maintenance period beyond traditional on schedule or time based maintenance. Visual inspection of equipment is not included in this category, although it could be the trigger for an inspection of equipment with a sensor/device.

In trying to implement this technology, Enagas detected a lack of experience in OEM and operators regarding *Condition Based Maintenance (CBM)* for cryogenic equipment with the *sensors working in cryogenic conditions*.

To solve this problem, Enagas proposed, to the Technical Study Group of GIIGNL, the creation of a best practices document, on critical and specific equipment for LNG plants and based on terminal operator experience, that can be used as a reference.

1.2 Objectives

The aim of the work was *to benchmark the predictive maintenance policy* for *cryogenic LNG pumps*, on the LNG terminals of participating companies in this working group, with the final objective of finding the optimum design or configuration of the sensor and attached equipment to obtain reliable measurement of the condition of the LNG pump.

Non cryogenic equipment are outside the scope of work because it is thought that they are better known than cryogenic ones.

1.3 Scope of Work

The study group agreed to include in this initial scope of work:

- Type of sensor/technology used to monitor different type of equipment, or parts of it.
- Key parameters to be monitored and controlled.
- Location of the sensor in the equipment.
- Experience in the utilization of the different sensor/technology
- Strategies of Maintenance: on condition, time based,…
- Estimated cost savings in maintenance.
- Trade mark of sensor and providers.
- Other.

The result of the work is this document summarizing the experiences of the participant members on Predictive Maintenance of cryogenic LNG pumps.

An additional topic has been to identify the type of BOG compressor used and the type of sensor/technology used to monitor it, to study the possibility of launching a future extension of this work.

1.4 Organization

The *Groupe International des Importateurs de Gaz Natural Liquéfié (GIIGNL)*, is a non-profit organization founded in December 1971 and has its central office located in Paris. It is composed of 51 member companies from over 16 countries (in North America, Asia and Europe) that are involved in the importation of Liquefied Natural Gas (LNG).

GIIGNL's main objectives are to promote the development of activities related to LNG: purchasing, importing, processing, transportation, handling, regasification and various uses of LNG. To this purpose, the Group provides an overview of the state-of-the art technology in the LNG industry and its general economic state in order to enhance facility operations, to diversify contractual techniques, to develop positions to be taken in international agencies, and so on.

The GIIGNL Technical Study Group is a consortium of GIIGNL member companies that meet on a semi annual basis to review, investigate and report on technical issues associated with the operation of LNG facilities worldwide. The group is required to report on its activities back to the GIIGNL General Assembly on an annual basis. This group commissions studies and appoints working groups to report on issues and topics which are pertinent to LNG operations.

The Predictive Benchmarking Maintenance (PMB) group was formed in May 2009 following a call to the Technical Study Group for interested parties at the April 2009 Technical Study Group meeting in Bilbao, Spain. It was agreed that Enagás would lead this benchmarking study and would prepare a scope of work.

Finally, the following companies joined the PMB group, agreed on the scope of work and participated in the its development:

- El Paso, (United States of America)
- Elengy, GdF SUEZ (France)
- Enagas (Spain).
- Fluxys LNG (Belgium)
- GNL Italia, (Italy)
- National Grid (United Kingdom)
- Osaka Gas, (Japan)
- Sempra LNG (United Stated of America)
- Tokyo Gas (Japan)

Additionally, some answers to the initial questionnaire were received from other LNG terminal operators on the Iberian Peninsula.

- REN Atlantico (Portugal)
- SAGGAS (Spain)

1.5 Study Timeline

April 2009: TSG45 Bilbao, Spain:
Green light from the Technical Study Group to start the project after the presentation of the preliminary scope of work developed for the PMB Study Group

May 2009: Madrid, Spain:
Kick-off meeting of the working group.
Definitive agreement on the scope of work by participants.
Development of Questionnaire 1 to gather information on LNG pumps, low and high pressure, and boil-off compressors.

November 2009: Marseille, France:
Review of answers to Questionnaire 1.
Agreement on the additional questions to ask to participating companies: Questionnaire 2.
Presentation of an additional questionnaire on boil-off compressors due to the dispersion in the answer to Questionnaire 1.

February 2010: Madrid, Spain:
Revision of Questionnaire 2 answers.
Presentation and agreement of the initial conclusions.
Presentation of successful case stories on CBM by Tokyo Gas and Osaka Gas.

May 2010: Panigaglia, Italy:
Revision of the content and first draft of the Group Report.
Presentation of case story in CBM by GNL Italia.
Decision on how to proceed in future.

May to July 2010: drafting and comments to Final Report by PMB Group members.

July 2010. Issuing of Final Draft Report from the working group for comments of the Technical Study Group members.

January 2011. Issuing of 2nd Final Draft Report from the working group for final comments of the Technical Study Group members.

December 2011. Issuing of Final Report to GIIGNL.

2. Key Definitions and Explanations

The aim of this chapter is to define and clarify some terms used in the report and needed in the different sections of it.

2.1 Definitions

CBM: Condition Based Maintenance. The maintenance of the pump is purely on condition, it means., the pump is maintained working until the vibration detector or any other monitoring parameter gives an alarm level in order to stop the pump prior to its failure. Pump shutdown can be automatic or not. For the purpose of this report, the monitoring parameter is the vibration measurement with one/two accelerometer sensors.

Predictive Maintenance: for the purpose of this report is a Condition Based Maintenance or On Condition Maintenance.

MIXED. The pump is working until a predefined number of hours. The CMB system is mainly used for checking that everything is working right in the meantime, it means, checking that no parameter has exceeded the alarm threshold.

TBM: *Time Based Maintenance*. The pump is working until a predefined number of hours. If a CBM system is installed, this is not used at all due to any reason, i.e., lack of confidence in it.

LOW PRESSURE LNG PUMP: Normally an LNG pump working up to 10 bar as a first stage of the LNG pressurisation process prior to regasification. Depending on the LNG plant design, such low pressure LNG pump may or may not be present. In the older LNG plants there are often no low pressure pumps. Known as well as *PRIMARY PUMPING SYSTEM*.

HIGH PRESSURE LNG PUMP: LNG pump pressurising the LNG up to the regasification pressure. As well known as *SECONDARY PUMPING SYSTEM*.

IN-TANK LNG PUMP: Low pressure pump installed in the pit of the LNG tank. For this reason any sensor installed on the pump is submerged in LNG. It is always present in modern designed LNG plant.

EX-TANK LNG PUMP: High pressure pump installed in a pot outside the LNG tank. Sensor to control the pump can be submerged in LNG or installed outside this.

SENSOR: in this report means the accelerometer used to measure the vibration.

VIBRATION: is the measure of state of the pump with the sensor. Levels above a predefined threshold means that the pump components are starting to wear/deteriorate.

MTBM: Mean Time Between Maintenance, in this case referred to the maintenance of the LNG pump and the electric motor, not any other equipment (valves, control devices, …) attached to them.

MTBF: Mean Time Between Failures, in this case referred to the failures of the LNG pump and the electric motor, not any other equipment (valves, control devices, …) attached to them.

2.2 Sensor location on LNG pumps

One of the findings of the work done is that the sensors utilised to monitor the LNG pumps are located in different places: in the pump itself or the assembly formed by the pump at the attached equipments (Figure 1). A particular case of one of the participants to locate two accelerometer to control an in-tank pump is to install one directly attached to the pump and another one attached to the pump pit outside the tank (Figure 2).

In this study, two possible location for the sensor have been defined:

- Submerged in LNG: directly attached to the LNG pump, the sensor is working in cryogenic condition. This location is possible for in-tank and ex-tank pumps (Figure 3, 4 and 5).

- Non submerged in LNG: the sensor is not directly attached to the LNG pump. The exact location can be in multiples places around the LNG pot and the equipment attached to this (Figure 6).

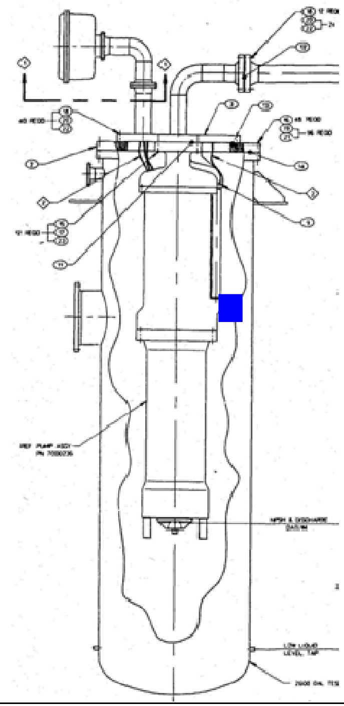
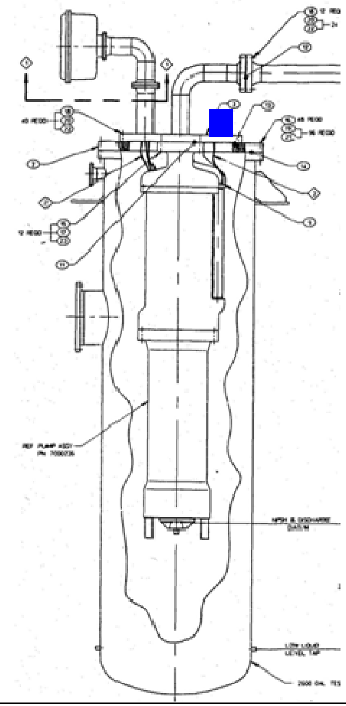
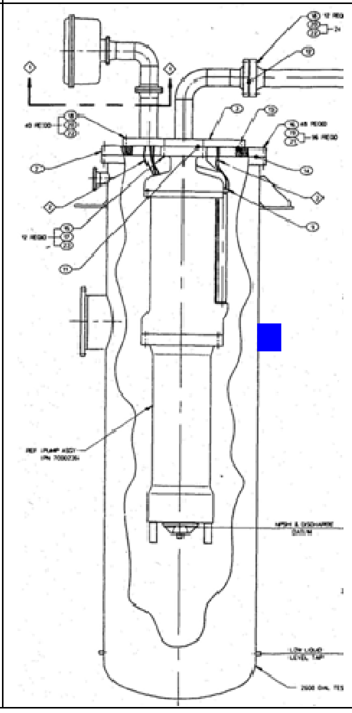
Submerged in LNG	Non Submerged in LNG	
Directly attached to the pump	*Attached to the flange*	*Attached to pump can/pot*
		

Figure 1.- Position of accelerometer in LNG pump.

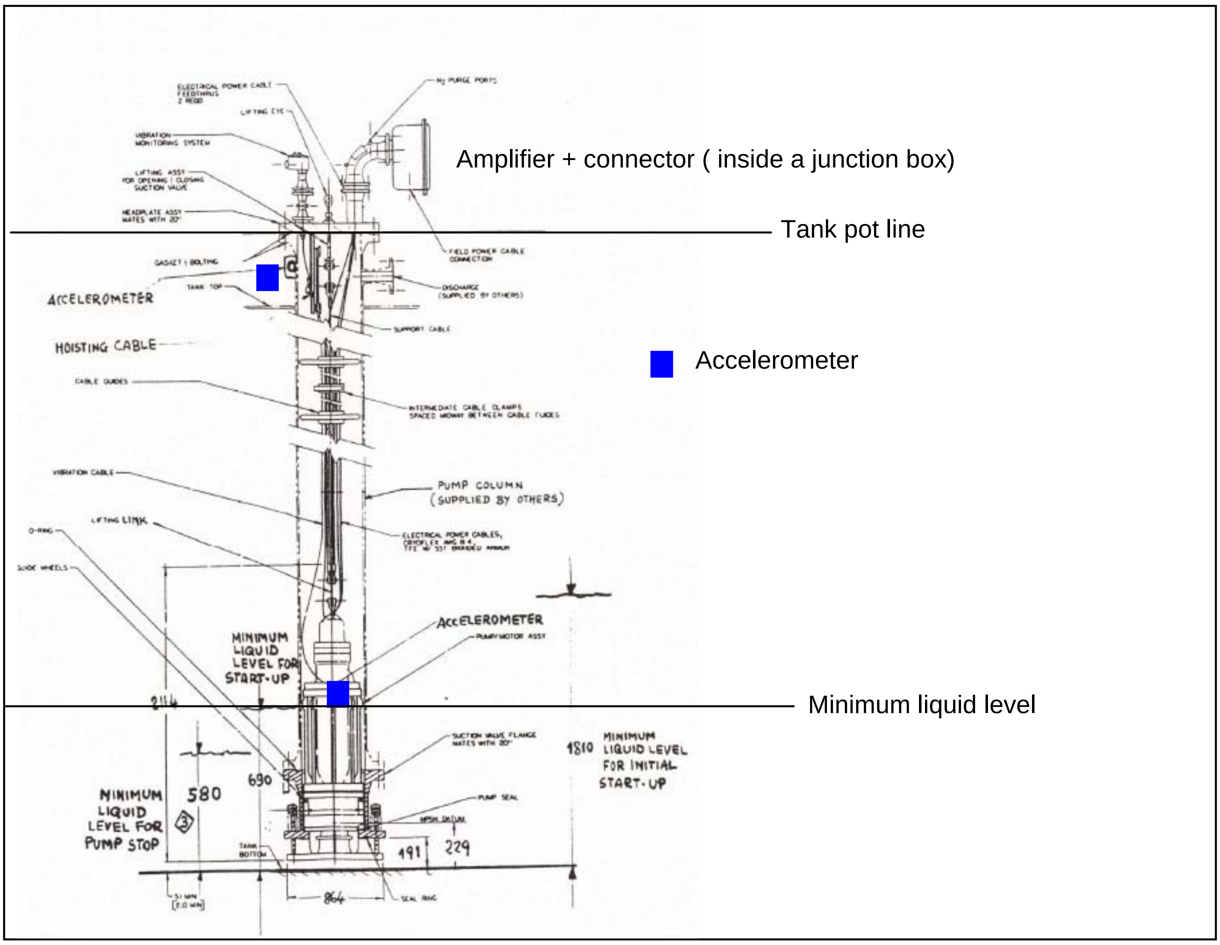


Figure 2.- Position of accelerometers for a particular in-tank LNG pump, one submerged in the LNG and one outside the LNG.

Figure 3.- Accelerometer directly attached to the LNG pump (an ex-tank pump in this case). Accelerometer in contact with LNG.

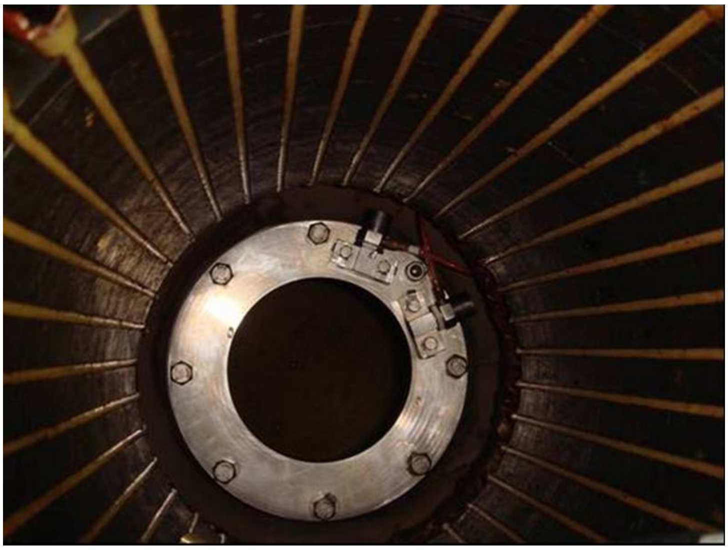


Figure 4.- Accelerometer directly attached to an internal part of the LNG pump (an in-tank pump in this case). Accelerometer in contact with LNG.

Figure 5.- Accelerometer directly attached to the LNG pump (an in-tank pump in this case). Accelerometer in contact with LNG.

Figure 6.- Accelerometer not directly attached to the LNG pump. Attached to the pump pot in this case.

2.3 LNG pump lay out

Another important point to distinguish between low and high pressure pumps was to take into account the history of the participating LNG Terminals in the study. The design of the older ones was quite different, some older terminals have no in-tank pumps at all and another has several pumps in series to reach the required send-out pressure.

Four lay outs have been identified (some are a variation of the other).

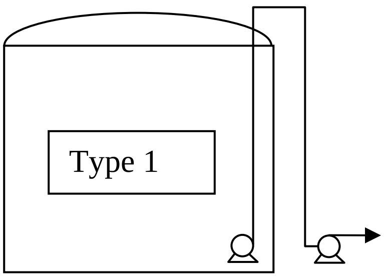


Figure 7.- Typical design for a modern LNG plant: in-tank pump (low pressure) and ex-tank pump (high pressure).

Figure 8.- Typical design for an old LNG plant: ex-tank pump only.

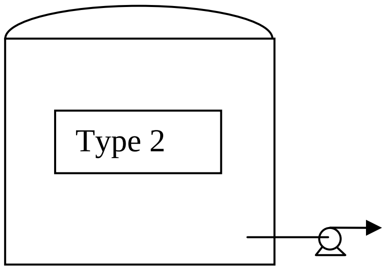


Figure 9.- Design with an in-tank pump (low pressure) and two ex-tank pumps in series (high pressure).

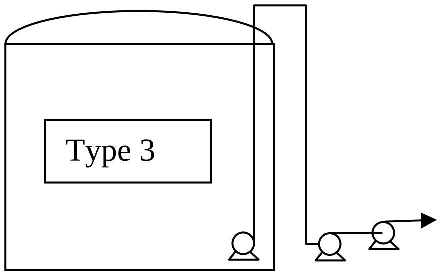
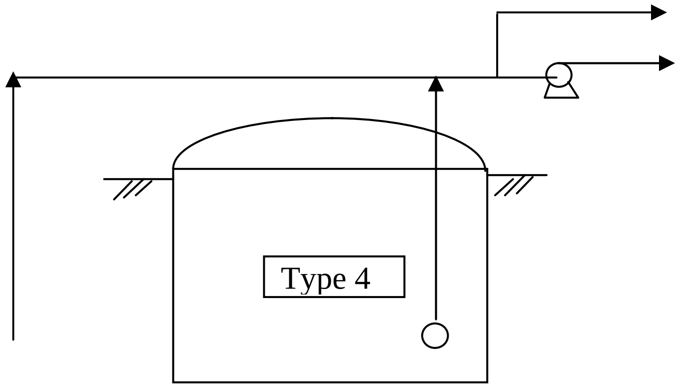


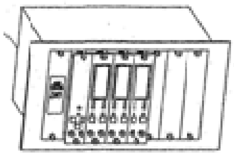
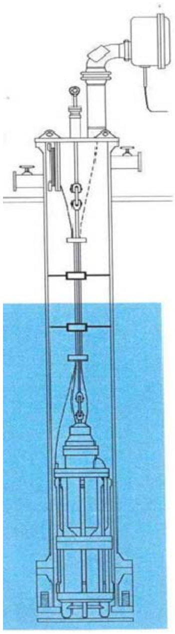
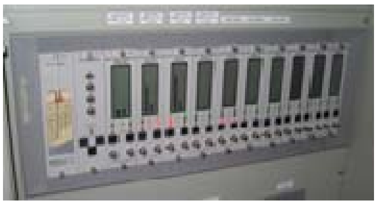
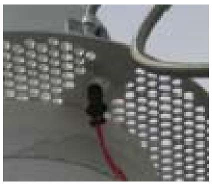
Figure 10.- Typical design for a modern LNG plant, with different send-our pressure: in-tank pump (low pressure) and ex-tank pump optional (high pressure).



2.4 Components of the predictive maintenance system

The components of a preventive maintenance system are shown in Table 1 for a submerged accelerometer. In case of a non submerged accelerometer, cryogenic cables and connectors may not be needed.

Table 1.- Components of the predictive maintenance system (for a submerged accelerometer in this case).

<table>
<tr><td rowspan="5">
Connected to rack
⇧

LNG pump
(in-tank in the example)</td><td></td><td>RACK:
To collect the signal and to analyse it (optional).</td></tr>
<tr><td></td><td>AMPLIFIER:
To amplify the accelerometer signal prior to send it to the rack.</td></tr>
<tr><td></td><td>CONNECTOR:
To make the transition from the gas section of the submerged accelerometer to the ambient atmosphere section.</td></tr>
<tr><td></td><td>CRYOGENIC CABLE:
To transmit the signal from the accelerometer to the connector all immersed in LNG for submerged sensor.</td></tr>
<tr><td></td><td>ACCELEROMETER:
a probe mounted on or in a rotating machine to produce a monitoring signal of the vibrations; this signal can be used to produce an alarm to warn for excessive vibrations levels</td></tr>
</table>

3. Information collected on predictive maintenance

In order to perform the work, the PMB group prepared several questionnaires that were answered by the participants. These questionnaires are the main result of the work because they reflect predictive maintenance practices of each participating terminals. The following sections describe the content of the questionnaires and the main results.

3.1 Questionnaire 1 on LNG pumps

The questionnaire was agreed upon at the kick off meeting of the group and was sent to the working group at the beginning of June 2009. The other Portuguese and Spanish LNG terminals were invited to participate in the work as well. The content of the questionnaire is shown in Appendix 1.

Questionnaires were received from 11 companies, comprising 15 LNG Import terminals:

- Elengy (GdF suez): Montoir de Bretagne (F)
- Enagás: Huelva, Cartagena (E)
- Fluxys: Zeebrugge (B)
- GNL Italia: Panigaglia (I)
- National Grid: Grain LNG (GB)
- Osaka Gas: Senboku 2, Himeji (J)
- REN Atlantico: Sines (P)
- SAGGAS: Sagunto (E)
- Sempra LNG: Energía Costa Azul (USA)
- Southern LNG/El Paso: Elba Island (USA)
- Tokyo Gas: Negishi, Sodegaura, Ohgishima (J)

The information gathered was analysed during the meeting held in November 2009. Enagas presented the answer to the questionnaires received and the first analysis done focusing on LNG pumps.

Tables 2 and 3 show the in-tank and ex-tank LNG pumps models used by the different companies. The tables includes, as well, the MTBM, MTBF, maintenance strategy (CBM/MIXED/TBM) and the general performance of this for each pump, according to the questionnaires answers. The questionnaire gathers information on 207 in-tank pumps and 168 ex-tank pumps. Figure 11 and 12 show the percentage of in-tank and ex-tank pumps with a CBM system installed, 56 % and 69 % respectively. Figure 13 and 14 show the performance of the monitoring system according to the answers of the participants.

The answers represented in the tables and figures show that a majority of the companies have CBM systems in place and these are working properly.

Figure 15 and 16 provide information about the trademark of the rack installed to monitor the CBM system.

Figure 17 shows the compliance of the LNG pump with API 670[1].

Summarising, the main findings are:

- From the analysis of the answers it appears that Sempra, Osaka Gas, Tokyo Gas and GNL Italia rely on CBM while other participants do not, for various reasons.

From the analysis of these answers, some questions needed to be clarified:

- Architecture of the system used by each participant:
  - Sensor.
  - Type of cable to transmit the signal.
  - Receptor/rack.
  - Presence of amplifier.
  - Type of connector.

- To clarify if all the system components are supplied by the equipment vendor, or if each piece of it is purchased independently and assembled by the participants.

- To clarify the meaning of CBM/MIXED/TBM for each participant. From the answer received, it seems that the meaning is not the same for everybody.

- Moreover, it is important to know the actual position of the pumps in the LNG process line, because some differences are identified from one participant to another (see type of pump lay out in 2.3)

In order to try to clarify these issues identified during the meeting, it was agreed that Enagas would prepare a new questionnaire (Questionnaire 2).

[1] API STD 670 Machinery Protection Systems

Table 2.- IN-TANK LNG pumps used by participating terminals.

TRADEMARK	MODEL	NUMBER	MTBM (average) (h)	MTBF (average) (h)	MAINTENANCE STRATEGY	PERFORMER MONITORING SYSTEM
CARTER	622463048-418	10	7 700	5 000	TIME	BAD
	6189L4	10	20 000	13 200	MIXED	GOOD
	60731L6	9	20 000	28 100	MIXED	GOOD
	6410L5-2740	10	40 000 or 25 000	19 350	MIXED	GOOD
	60711L4-3048	7	25 000	9 700	MIXED	GOOD
	60734L3-3048	9	15 000	23 900	MIXED	GOOD
	60731L4-3048	4	25 000	10 800	MIXED	GOOD
	60734R3-3048	4	40 000	23 410	MIXED	GOOD
	60788L3-3456	8	40 000	36 800	MIXED	GOOD
	61145-3056	4	40 000	20 800	MIXED	GOOD
	6224H-3048-405	8	6 000	No available	TIME	n/ap
	60777	9	14 000		TIME	REGULAR
	6820R4-47545-191	3	No available	180	MIXED	GOOD
	60882R3-3555	3	14 500	No apply	TIME	REGULAR
CRYOSTAR	RP20*8*11/Q2S	1	11 400		TIME	BAD
	RP24*10*13/S2S	9	No available	542	MIXED	GOOD
	RP24*8*11	3	12 000		RUNNING PARAMETERS	BAD
NIKKISO	6224L1-R155F	1				BAD
	60788L3-R185F	2	40 000	43 400	MIXED	GOOD
	60882L2-R355F	6	No available	No available	MIXED	BAD
	60639L3-R155F	6	No history	No history	MIXED	GOOD
EBARA	6ECR/09M	2			CBM	GOOD
	10ECR/18	4			CBM	GOOD
	10ECR/24	6	No history	No history	CBM	REGULAR
	8ECR/122	2	50 000	41 500	MIXED	GOOD
	6ECC/15	1	50 000	31 700	MIXED	GOOD
	6ECR/152C	2	12 000	No apply	RUNNING PARAMETERS	BAD
		4	14 500	No apply	TIME	BAD
	8ECR/152	3	14 500	No apply	TIME	BAD
		6	12 000		RUNNING PARAMETERS	BAD
	4ECR/123	5	12 000		RUNNING PARAMETERS	BAD
		4	14 500	No apply	TIME	BAD
	8ECC-15	2	No available	No failures	MIXED	GOOD
SHINKO	SMR200	6	12 000		CBM	GOOD
HITACHI	BGM-MV (1)	6	50 000	20 100	MIXED	GOOD
	BGM-MV (2)	4	50 000	34 800	MIXED	GOOD
	BMG-MV (3)	2	40 000	25 900	MIXED	GOOD
	BGM-MV (4)	10	50 000	27 000	MIXED	GOOD
AIRCO	10X23	6	No available	No failures	CBM	
	6X21	4	No available	No failures	CBM	

Table 3.- EX-TANK LNG pumps used by participating terminals..

TRADEMARK	MODEL	NUMBER	MTBM (average) (h)	MTBF (average) (h)	MAINTENANCE STRATEGY	PERFORMER MONITORING SYSTEM
CARTER	60788L16-42966-34	3	8 100	8 200	MIXED	REGULAR/BAD
	60777L16-49144-11	6	6 400	5 400	MIXED	REGULAR/BAD
	60731L9-3768-18	16	3 500		CBM	GOOD
	60788R15-4248	4	No maintenance		RUNNING PARAMETERS	BAD
	60788L13-4272-13	7	6 000	No available	TIME	n/ap
	60839	8	14 000		TIME	REGULAR
	60731L14-3468	9	25 000	10 300	MIXED	GOOD
	60788R10	2	20 000	9 000	MIXED	GOOD
BINGHAM	VERTICAL IN BARREL	8				
SHINKO	SMB100-10	22	No apply	14 300	CBM	GOOD
	SBM100-10	9	20 000		CBM	GOOD
AIRCO	6X13-11	4	2 000	2 000	MIXED	GOOD
	4X13-8STG	5	12 000		CBM	GOOD
NIKKISO	60839L17-P1150F	7	No history	No history	MIXED	GOOD
	60723L14-P1700F	6	8 000	No history	TIME	BAD
HITACHI	BGM-MV (5)	6	40 000	18 000	MIXED	GOOD
	BGM-MV (6)	1	50 000	No history	MIXED	GOOD
	BGM-MV (7)	3	50 000	No history	MIXED	GOOD
EBARA	6ECC-1511	7	18 000		RUNNING PARAMETERS	BAD
	6ECC-158	3	20 000	12 600	MIXED	GOOD
	8ECC-1211	7	No history	No history	CBM	REGULAR
	6ECC-159	12	15 000	No apply	TIME	BAD
DAVID BROWN	6x8x17$^{1/2}$ JVCR 24/STG	8	No available	426 (including auxiliary equipment)	MIXED	GOOD
SULZER	8x12x22 AB JVCRD-V	5	No available	500 (including auxiliary equipment)	MIXED	GOOD

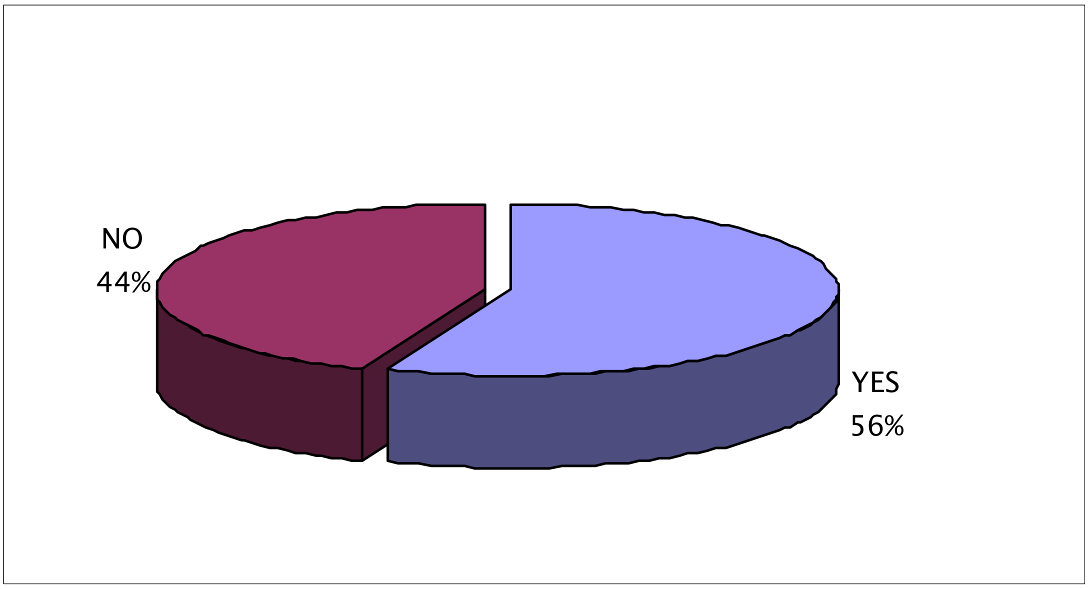


Figure 11.- IN-TANK LNG pump with CBM system installed.

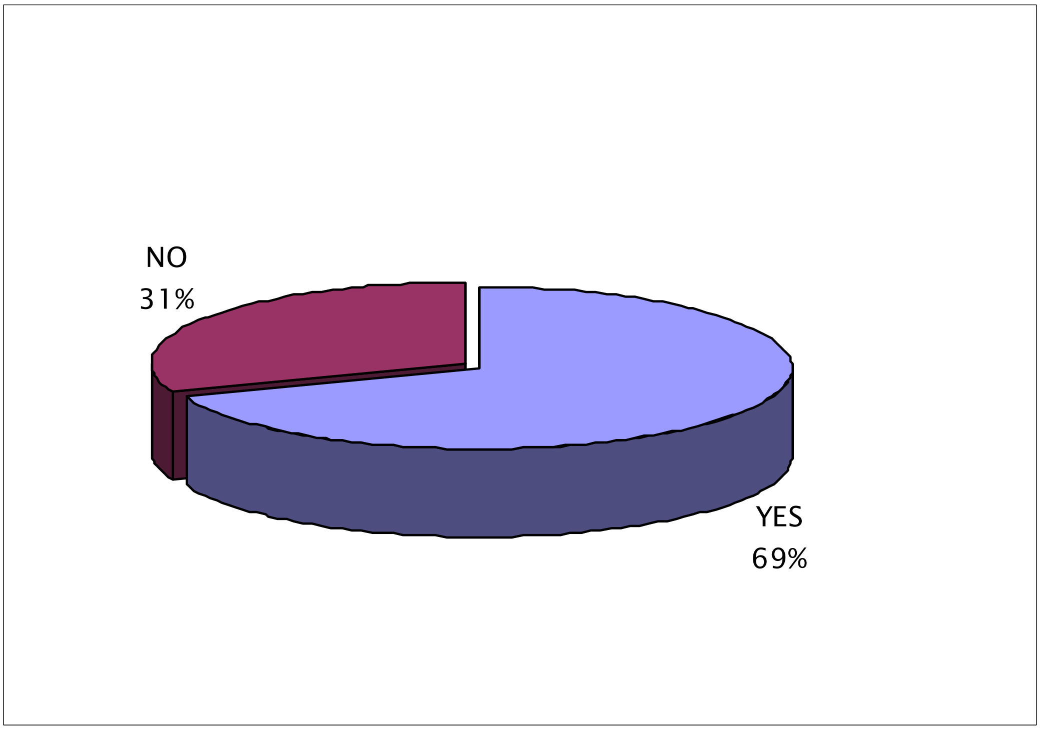


Figure 12.- EX-TANK LNG pump with CBM system installed.

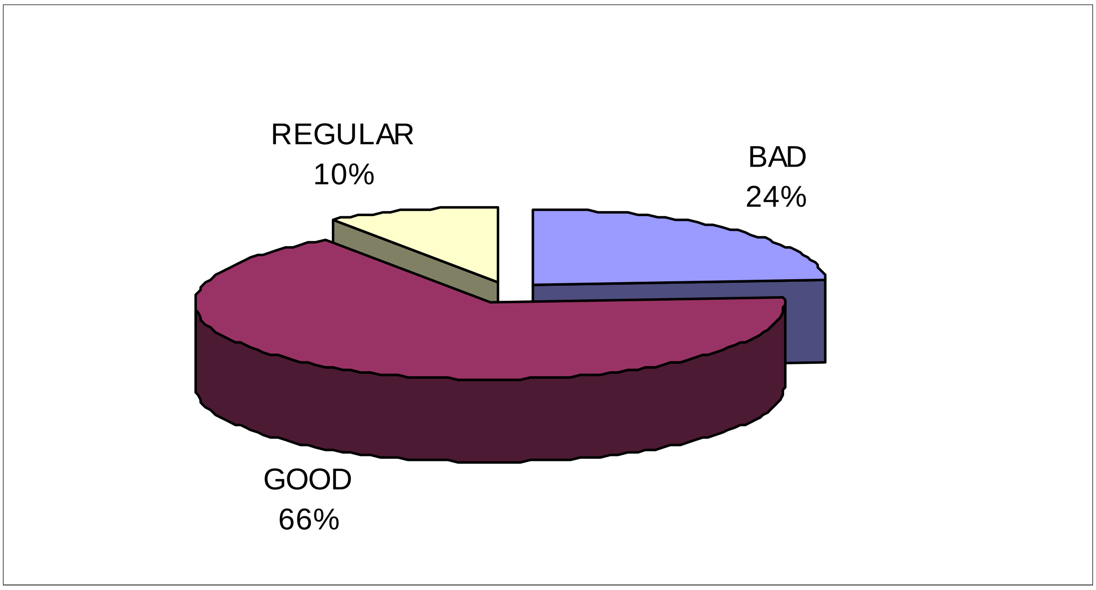


Figure 13.- IN-TANK LNG pump, performance of the CBM system installed.

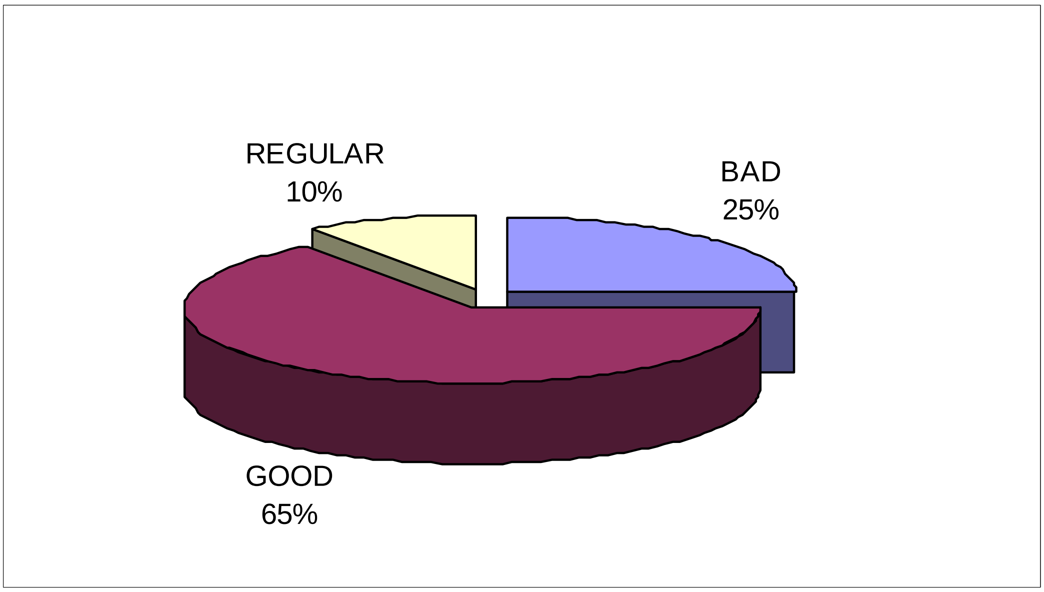


Figure 14- EX-TANK LNG pump, performance of the CBM system installed.

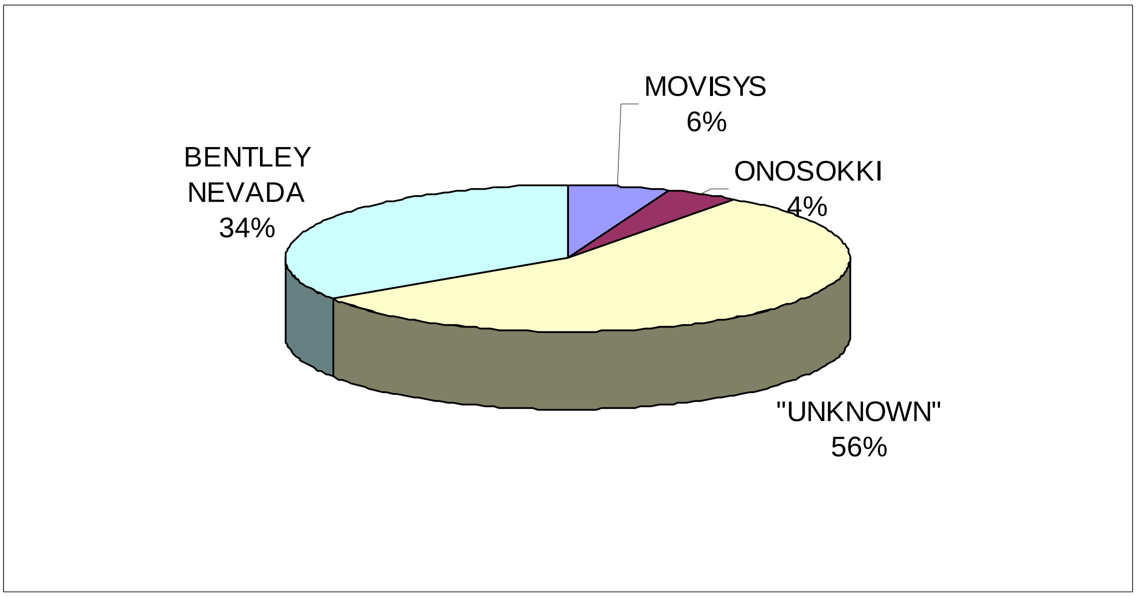


Figure 15.- IN-TANK LNG pump, rack trademark installed with the CBM system.

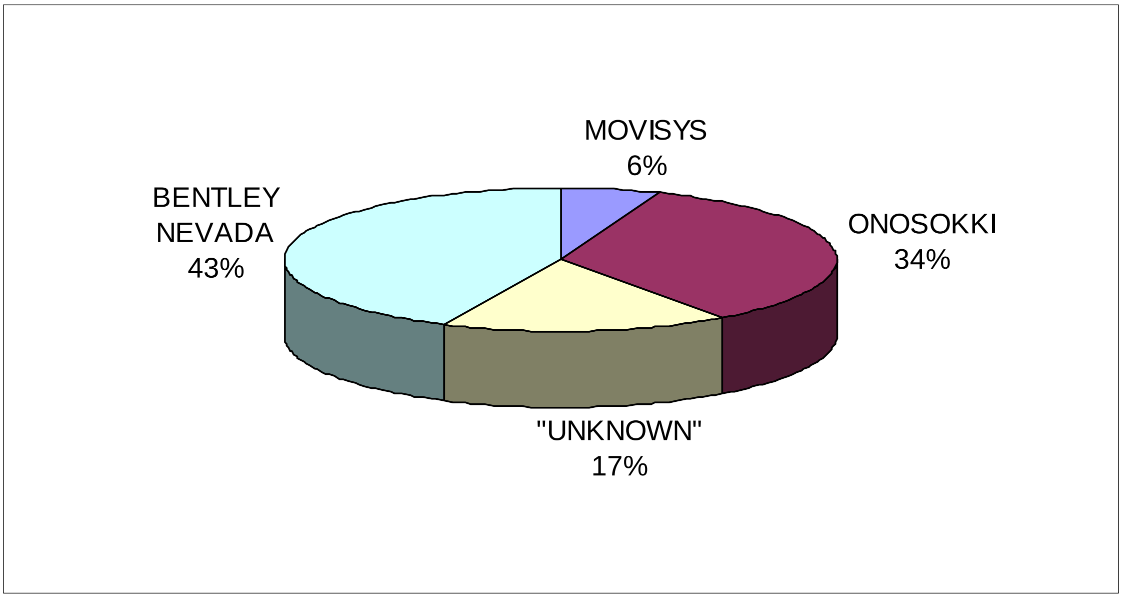


Figure 16.- EX-TANK LNG pump, rack trademark installed with the CBM system.

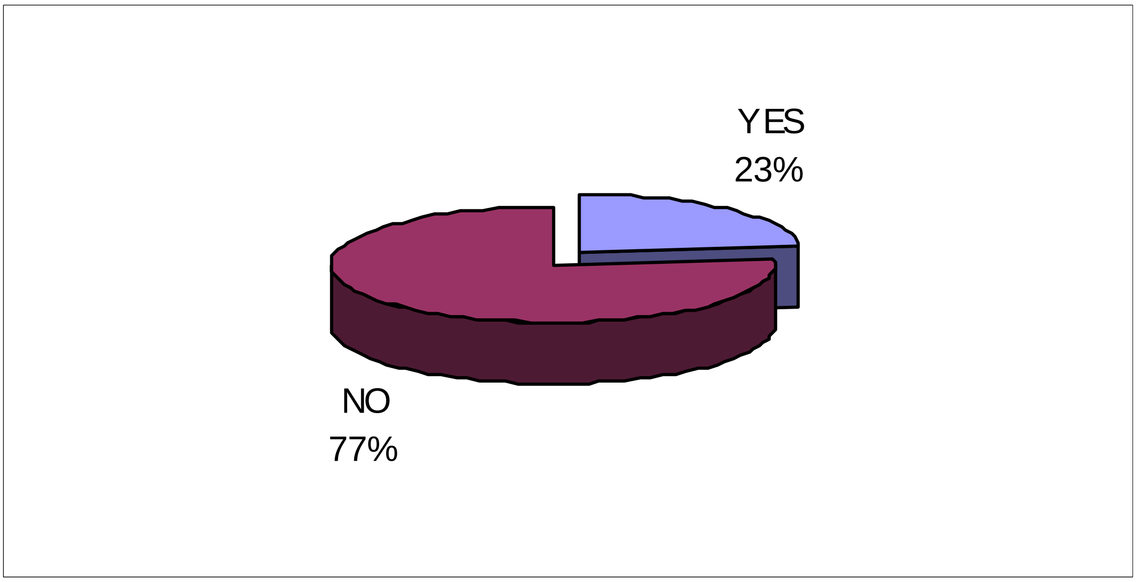


Figure 17.- Compliance with API 670 of the CBM system installed in each terminal.

3.2 Questionnaire 2 on LNG pumps

As agreed in the meeting in November 2009, Enagas prepared a new questionnaire in order to complete the information gathered in Questionnaire 1. The information received was analysed at the meeting in February 2010. Answers were received from all the participant in the group. This questionnaire was not sent to third parties. The content of the questionnaire is shown in Appendix 2.

Enagas presented the summary of the answers received to Questionnaire 2 and the analysis done. This questionnaire mainly focused on obtaining additional information on LNG pumps and its monitoring system.

The questionnaire answers contained a lot of information. However, this was difficult to analyse and to find clear conclusions because the structure of the questionnaire was quite open and this produced a dispersion in the type of answers.

One thing highlighted by the questionnaire answers was the fact that the *type of LNG pumps used by the different terminals are highly influenced by the terminal history*, because some terminals have quite an old design (Panigaglia and some Japanese) while other have a modern design where the difference between low and high pressure pumps is very clear.

Table 4 shows the type of CBM components used in each terminal. This table informs, as well, about the LNG pump architecture in each terminal (refer to 2.3).

Table 5 shows the position of the accelerometer (submerged in LNG or not), the type of maintenance and the performance of the CBM for in-tank and ex-tank pumps in each terminal.

Table 6 shows the terminals which are relying on a CBM system and its performance for submerged accelerometers.

The answer to this questionnaire highlighted that, due to the high variety of terminal designs and in order to formulate a conclusion, it is more important to distinguish between IN-TANK/EX-TANK pumps than LOW PRESSURE/HIGH PRESSURE pumps (this point has been followed along this report, as it can be seen in the previous chapters). In-tank or ex-tank has a clear influence on the position of the accelerometer, which is important for the successful operation of the CBM equipment:

- Submerged in LNG, directly attached to the pump.
- Non submerged in LNG: attached directly/indirectly in any other way to the pump.
- All in-tank pumps have submerged accelerometers.
- In ex-tank pumps, accelerometers can be located in a submerged or external environment.

According to this classification, from the questionnaires it is deduced that only for GNL Italia and TG/Ohgishima terminals, submerged accelerometer are declared to work properly, i.e., CBM is used in the maintenance of LNG pumps. Sempra claims to use CBM for submerged accelerometers but its history is too short (the terminal is only two years old) to obtain sufficient data for clear conclusions. For non submerged accelerometers several successful CBM experiences are declared.

During the meeting in February 2010, TG informed that they recently changed from the CBM policy to mixed or TBM due to different reasons.

As a conclusion, from the analysis of all the information gathered, there is not any LNG pump (IN or EX TANK) relying on CBM if the accelerometer is submerged, except in the case of GNL Italia.

Regarding the question about maintenance of LNG pumps, most of the answers show that maintenance practices are more or less the same in all the terminals:
1st – Disassembling the pump.
2nd – Measurement of tolerances of wear rings, bushing, rotor alignment, …, and visual inspection of diffuser, impeller and other internal parts.
3rd – Reassembling the pump:
- Internal components no t within tolerances are replaced by new ones.
- To install new bearings.
- To balance the rotor.

Except for some minor standard spares, all the participants use original spare parts from the pump manufacturers.

After the meeting in February, as a conclusion of the Questionnaire 2 analysis, the following two facts were clear:
- *Currently, NOBODY is using CBM for IN TANK pumps, i.e, submerged accelerometer*, except GNL Italia.
- After analysing the questionnaires and the meeting discussions,it became clear that Tokyo Gas and Osaka Gas are the only terminals confirming that the CBM monitoring system provide stable signal and credible measurements for submerged accelerometer installed on IN TANK pumps.

Table 4.- Type LNG pump architecture and CBM components for each terminal.

TERMINAL	TYPE	PUMP MODEL	RACK	AMPLIFIER	CONNECTORS	CRYOGENICS CABLE	ACCELEROM.
SEMPRA	1	EBARA, in tank	B-N 3500	B-N CA24145-02	Hawke	not defined (EBARA	PCB 8070252 PER 15492-01
	1	EBARA, send out	B-N 3500	B-N CA24145-02	Hawke	Okonite, Triad 18 Gwc	PCB 8070252 PER 15492-01
OSAKA GAS: Himeji	2	SHINKO, send out	Ono Sokki	tipe A: San Denshi	No defined	No defined	San Denshi
	2	SHINKO, send out	Ono Sokki	tipe B: no amplif.	Ono Sokki	Ono Sokki	Ono Sokki
OSAKA GAS: Senboku II	1 & 2	low pressure	Ono Sokki	Tokyo Dengyo	Tokyo Dengyo	Tokyo Dengyo	Tokyo Dengyo
		send out	Ono Sokki	Tokyo Dengyo	Tokyo Dengyo	Tokyo Dengyo	Tokyo Dengyo
ELENGY	1	Low pressure	MOVISYS	No amplif.	BNC	Not defined	PCB 351M01
	1	High pressure	MOVISYS	No amplif.	BNC	Not defined	PCB 351M01
ELBA ISLAND	2	EBARA 8ECC-15 send out	B-N 3500	B-N CA24145	B-N	Ebar	PCB 351M20
ENAGAS: Cartagena Huelva	1	EBARA (low & high pres.)	B-N 3300	B-N	ITT & Amphenol	Ebara	PCB351SM15 PCB351M20
		CARTER (low pressure)	B-N 3500	No amplif.	ITT and Amphenol	Carter	Dytran 3190A6
GNL ITALIA	3	EBARA EBARA BINGHAM (all of them in tank)	B-N 3300	No amplif.	No connectors	Ebara	PCB351M12
FLUXYS LNG	1	CRYOSTAR/ CARTER (low pressure)	B-N 3300/3500	None	MIL-MS3106/2	Coax RGL400 TPT	PCB351/ Wilconox/ PCB628
		BROWN/SULZER (high pressure)			MIL	none	B-N 330400-2-5
NATIONAL GRID	1	NIKKISO (low pressure)	B-N 3500	None	Nikkiso TB3206A	Nikkiso 3 conductor shield cable	PCB J351
		NIKKISO (high pressure)					PCB J351/ B-N330400
TOKYO GAS: Negishi Ogishima Sodegaura	2 & 4	CARTER NIKKISO EBARA HITACHI	TGE NISHIKAWA YOKOGAWA	Tokyo Dengyo Aco	Tokyo Dengyo Aco	Tokyo Dengyo Aco	Tokyo Dengyo 215E Aco d-533

B-N: Bentley Nevada

Table 5.- Position of accelerometer, typo of maintenance and general performance of CBM Maintenance for each terminal.

TERMINAL	POSITION OF PUMP	LOCATION OF ACCELEROMETER	TYPE OF MAINTENANCE	GENERAL PERFORMANCE OF CBM
SEMPRA	IN TANK	Submerged	CBM	REGULAR
	EX TANK	Submerged	CBM	REGULAR
OSAKA GAS HIMEJI	IN TANK	Submerged	MIXED	-
	EX TANK	Non submerged	CBM	GOOD
OSAKA GAS SENBOKU	IN TANK	Submerged	MIXED	-
	EX TANK	Non submerged	CBM	GOOD
ELENGY	IN TANK	Submerged	TBM	-
	EX TANK	Non submerged	MIXED	-
ELBA ISLAND	IN TANK			
	EX TANK	Non submerged	CBM	GOOD
ENAGAS: Cartagena Huelva	IN TANK	Submerged	TBM	-
	EX TANK	Submerged	TBM	-
GNL ITALIA	IN TANK	Submerged	CBM	GOOD
	EX TANK			
FLUXYS LNG	IN TANK	Submerged	MIXED	-
	EX TANK	Non submerged	CBM	GOOD
NATIONAL GRID	IN TANK	Submerged	MIXED	-
	EX TANK	Submerged/Non submerged	MIXED	-
TOKYO GAS: Negishi Ogishima Sodegaura	IN TANK	Submerged	MIXED/CBM	GOOD
	EX TANK	Submerged	MIXED	-

Table 6.- Terminals with a good performance of CBM for submerged accelerometers.

TERMINAL	POSITION OF PUMP	LOCATION OF ACCELEROMETER	TYPE OF MAINTENANCE	GENERAL PERFORMANCE OF CBM
SEMPRA	**IN TANK**	Submerged	CBM	REGULAR
	EX TANK	Submerged	CBM	REGULAR
OSAKA GAS: HIMEJI	IN TANK			
	EX TANK			
OSAKA GAS: SENBOKU	IN TANK			
	EX TANK			
ELENGY	IN TANK			
	EX TANK			
ELBA ISLAND	IN TANK			
	EX TANK			
ENAGAS: Cartagena Huelva	IN TANK			
	EX TANK			
GNL ITALIA	**IN TANK**	Submerged	CBM	GOOD
	EX TANK			
FLUXYS LNG	IN TANK			
	EX TANK			
NATIONAL GRID	IN TANK			
	EX TANK			
TOKYO GAS: OHGISHIMA	**IN TANK**	Submerged	CBM	GOOD
	EX TANK			

3.3 Boil-Off compressors questionnaire

The content of the questionnaire is shown in Appendix 3.

Objective of the questionnaire
To identify technological solutions that allows the review of current maintenance strategies by means of predictive solutions in order to improve the maintainability, a first step to improve the availability and reliability, and readiness of the boil-off compressors.

Currently, in the world, 72 Regasification Plants are in service (16 in Europe, 41 in Asia, and 15 in America). The Predictive Maintenance Benchmarking Group is formed by 15 Terminals. Their number, the diversity of their geographical location, and the wide age range gives confidence that this is a *representative sample*.

Answers to the BOG compressor questionnaire
All the members answer the questionnaire on BOG compressor sent by Enagas.

The main results are:

Type and number of machines:
- Reciprocating horizontal: 42 (79%)
- Reciprocating vertical: 7 (13%)
- Centrifugal: 2 (8%)
- Total: 51

According to the answers, the most common type of equipment is reciprocating and horizontal, Figure 18, although it is evidenced that most of new Plants (designed from 2000 onwards) and modifications of existing ones have reciprocating vertical compressors. Is the reason of this to avoid the main failure mode of horizontal ones? Because of their short time in operation, insufficient information about failure mode exist about alternative and vertical compressors.

Capacity:
- Reciprocating horizontal: 2500 – 20000 kg/h
- Reciprocating vertical: 4000 – 18000 kg/h
- Centrifugal: 15000 kg/h

Control System:
- Reciprocating type: cylinder valves
- Centrifugal type: anti-surge valve

Maintenance Strategy:
- Mostly preventive:
  - *Overhauls* with impacts on availability every 4000 h, 8000 h, 16000 h, ...
  - Because of the lack of reliability of rod drop monitoring systems, preventive periodic inspection of the rod drop condition have to be

scheduled. Only El Paso claims to have confidence in the rod drop system.

- Some support by predictive technologies:
    - Vibrations: a wide list of reference codes and standards exit, but not specific for this type of machines. Because of this, most companies only use this technology to assure the general protection of the machine. In some cases a portable vibration analyser with data collector is used for periodic analysis of vibrations at specific points of the compressor.
    - Rod drop: those that have such a monitoring system have it because of its design specification (from the initial start up), all of them are from GE Bentley - Nevada, but any of them gives information about the reliability of this monitoring system.
    - Except El Paso, no one has continuous monitoring systems for rod drop that is working properly.

Failure Mode (Figure 19):
- Rider Ring and rider pads: 96 %
- Valves: 3 % (spot failures)
- Other: 1 % (very low frequency of failures).

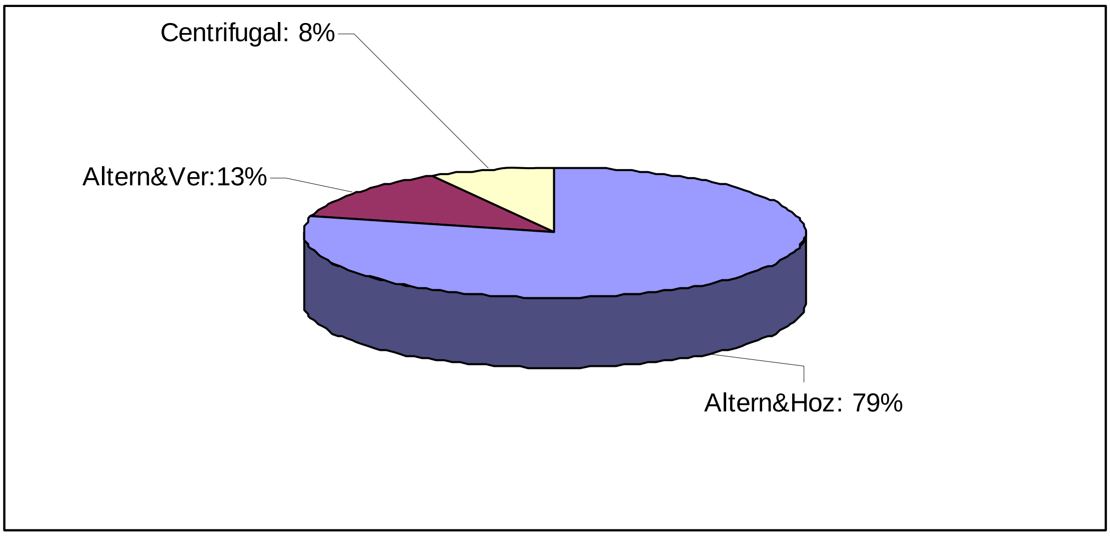


Figure 18.- Percentage of type of BOG compressor.

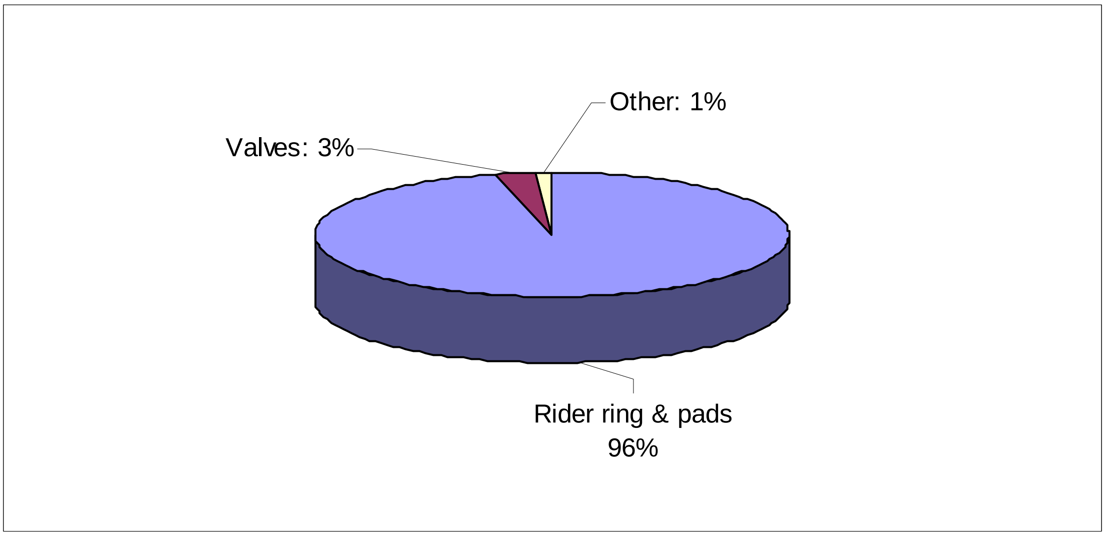


Figure 19.- Percentage of failure mode of BOG compressor.

4. Recommendations for CBM for LNG pumps

After the revision of the information gathered in the different questionnaires, the presentations and discussions held at the meetings of the PMB Group, some clear design and installation recommendations for a successful CBM system for LNG pumps have been developed.

The most important recommendations are indicated below (mainly based on Osaka Gas and Tokyo Gas presentations in February 2010 meeting):

1.- Components submerged in LNG have to follow a cryogenic technical specification.
This includes all the component in the measurement chain submerged in LNG: accelerometer, cable and connector.

2.- To minimise the noise in the sensor signal (Figure 20).
In order to fulfil this requirement, these recommendations have to be followed:
 (1) To install the field amplifier as close as possible to the sensor to minimize low level and high impedance signal line.
 (2) Piezoelectric element type accelerometer is more preferable than differential transformer type accelerometer.
 (3) In a long distance connection when a field amplifier is needed, the charge amplifier type has to be in accordance with the piezoelectric type sensor.
 (4) Osaka Gas is using low noise double shield coaxial cable to prevent external noise between accelerometer and amplifier with a satisfactory result.
 Other companies are using cryogenic twisted pair cable with satisfactory result as well.
 (5) *Sensor, cable and field amplifier* have to be designed and manufactured as one system.
 (6) To use twisted pair cables between the amplifier and the rack in the control room, not parallel cables, to avoid noise.
 (7) To check grounding condition. Single point grounding is essential to prevent external noise.

3.- The signal measured by the accelerometer should be stored in a data base to be able to process the recorded value with a specific software, in order to obtain different kind of information to determine the pump working condition:
- Velocity: instantaneous and trend.
- Acceleration: instantaneous and trend.
- Wave form.
- Spectrum (FFT[2]).

[2] FFT: Fast Fourier Transform.

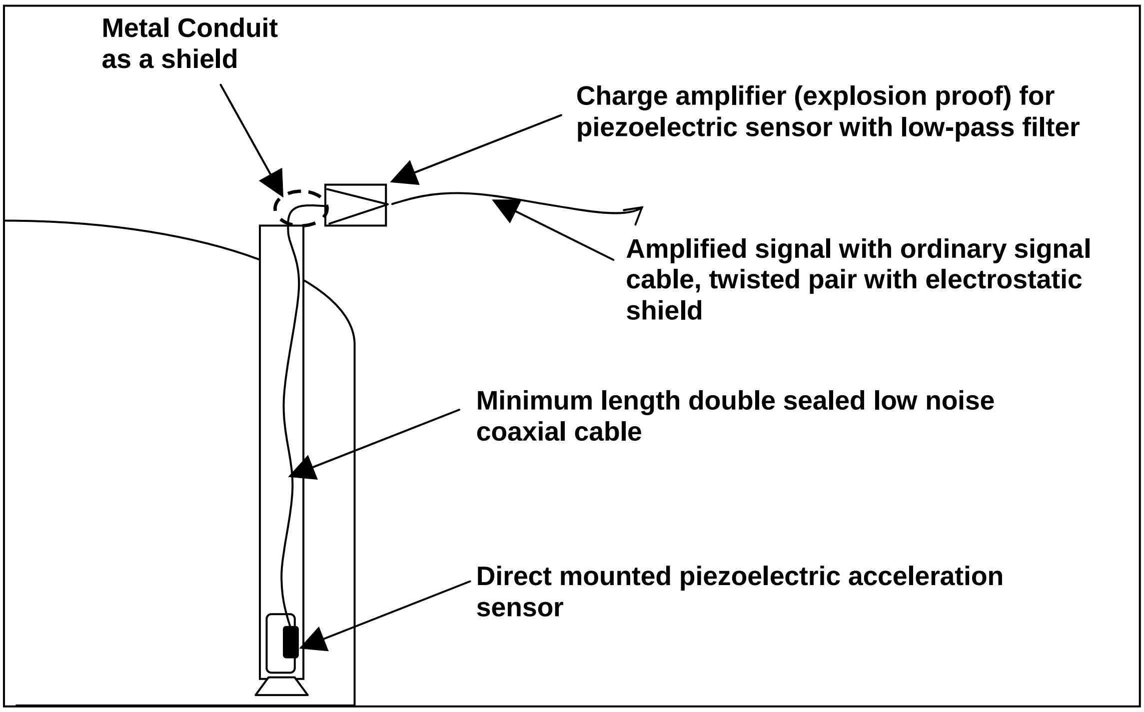


Figure 20.- Sketch of the sensor and attached equipment installation recommended.

5. Conclusions

From the information gathered by the group, the following conclusion can be determined:

1.- All working group companies have installed measurement systems for doing predictive maintenance of cryogenic equipment. The system can work open loop (signal/alarm only) or closed loop (high signal shut down the pump automatically).

2.- Currently only one company uses CBM for LNG pump with submerged accelerometer, i.e., measurements performed in cryogenic conditions, but it has no notion of the condition of the pumps because no mechanical maintenance has been performed up to now.

3.- Several companies are using CBM successfully for ex-tank LNG pump using non submerged accelerometer, i.e., not directly attached to the LNG pump.

4.- Several companies are relying on a MIXED maintenance strategy, i.e., the pumps are overhauled after a determined period of running hours and a CBM system is installed to monitor that the pump is working properly up to the determined period of time.

5.- There is no clear reason why the CBM is not a reliable strategy for maintenance of LNG pumps for most of the group companies, although there are some tips: signal quality, level of alarm (to use wave form and vibration spectrum, not only fix value), position of sensor, number of sensors, … Anyway, the installation of vibration measurement systems on pumps in cryogenic service is becoming more common, but to solve the problems associated with interference in the signals should be a development issue, so more operating experience is required to gather data to demonstrate the true benefits of CBM on this equipment.

6.- Anyway, it is important to have a reliable (stable and credible) signal from the sensor. In chapter 4 some basic recommendations are listed.

7.- No information on saving cost in maintenance activities has been finally collected by the group because some important aspects related to these have not been clarified in the information gathered and discussions held. There are many different type of pumps (trademark and model), very different MTBM, …, although the disparity in MTBM gives an idea of the possible saving cost in maintenance if CBM will become a reliable tool.

8.- At the final meeting of this PMB Group, it was decided to finish the current interchange of experiences on **LNG pumps** because no additional information can be obtained in further discussion.

Osaka Gas and Tokyo Gas offered to share its experience in CBM on the basis shown in Chapter 6.1.

Additionally, Fluxys and Enagas agreed to inform through the TSG about its test of an alternative monitoring system for CBM based on the measurement of electrical motor parameters to determine the mechanical condition of the pumps and its motor (see Appendix 4).

9. At the meeting on May 2010 of PMB Group, it was agreed to continue sharing information on **BOG and pipeline compressor** relating to CBM in these equipment, according to the suggestion made by Enagas in the terms specified in Chapter 6.2.

Finally, in the May 2010 meeting, it was agreed to cease the activities of PMB Group after writing the Final Report and to maintain future contact by e-mail and at the Technical Study Group meetings. The PMB Group could be recovered, if needed, in case that something new appears.

6. Next steps suggested by PMB group

The way to continue sharing experience on CBM, agreed at the meeting on May 2010, are indicated below.

6.1 LNG pump

As a consequence of the information gathered in the questionnaires and the discussions held at the different meetings, on the CBM system for submerged accelerometer for in-tank pumps, which seems to work properly, the following points seem to be clear:

- Osaka Gas and Tokyo Gas have a monitoring system with a stable signal and credible measurement for submerged accelerometer installed on in-tank pumps.
- The system used by GNL Italia works properly as well, but it needs to be confirmed after making mechanical maintenance of the pumps, i.e., after disassembly.
- An important difference between the Japanese and Italian systems is the level of alarm fixed to stop the pumps, the Japanese one is more conservative. Additionally, the accelerometers are mounted in different positions.

During the meeting held on 25th February 2010, the participants discussed different options to access to the technology of Osaka Gas and Tokyo gas and the pros and cons of them. Finally, Osaka Gas and Tokyo Gas presented at the meeting on 13th May 2010 their proposal to share their proprietary technology. These are the following:

<u>Osaka Gas position:</u>

It is not possible to make a unique offer to the group because its system is custom designed, based on Osaka Gas internal engineering experience.

Osaka Gas can offer collaboration on an individual basis to each interested company. Any interested company should contact the representative of Osaka Gas at the GIIGNL Technical Study Group for future talks.

<u>Tokyo Gas position:</u>

Tokyo Gas Engineering can offer different options depending on the needs of the interested companies:

- Specification of each equipment, including cable.
- Software and Signal processing.
- Diagnosis system itself.
- Diagnosis techniques.
- To supply the equipments/components of the whole system.
- Others.

Interested companies should contact the representative of Tokyo Gas at the GIIGNL Technical Study Group for future talks indicating its needs.

6.2 Compressors

The PMB Group decided to study both, BOG and pipeline compressors, by means of interchanging information by e-mail and presenting the results at the Technical Study Group meetings.

The following action plan was agreed:

- To collect additional information on BOG compressor maintenance. To do this, Enagas will send a new questionnaire (basically the already filled one with some additional fields):
  - Adding more details on the most frequently used monitoring technologies: vibration and rod drop.
  - To enlarge the number of companies interviewed (especially in order to increase the information about alternative and vertical compressors): for example, to get 100 % Spain = 50 % Europe.
- Enagas will provide information about its internal works to develop a vibration technology for predictive maintenance:
  - Vibration monitoring (any type of compressor):
    - To establish contact with TNO (EFRC[3] guidelines on vibration project).
  - Rod drop (only for alternative and horizontal compressors):
    - To develop a “Pilot Project” with reference suppliers (GE – Bentley & Nevada)
  - Once new information is available, Enagas will propose a new meeting to present the findings and to study future joint works to proceed.

[3] EFRC: European Forum Reciprocating Compressors

Appendix 1 : Questionnaire 1

The questionnaire was divided in three sections:

- LNG Low pressure pumps.
- LNG High pressure pumps.
- Boil-Off Gas compressor.

LNG LOW PRESSURE PUMPS

GIIGNL: Technical Study Group
Predictive Maintenance Benchmarking Group

LOW PRESSURE (IN TANK) PUMP QUESTIONNAIRE
Please, add additional columns if needed.
If needed for any celd, add the comments aparts.

Company:	
Terminal:	

Basic information of LNG pump				
	1	*2*	*3*	*4*
Trademark of LNG pump				
Model of LNG pump				
Number of pumps				
Design Pressure (barg)				
Flow rate (m3/h)				
Power (kW)				
Type start up (soft/direct)				
How long on operation (year of start up)				
Design MTBM (vendor recommendation)				
MTBM: max, aveg, min				
MTBF: max, aveg, min				
Number of Start/stop, frequency				
Running hours/year				

MTBM: Mean Time Between Maintenance
MTBF: Mean Time Between Failure

Specific information on CBM				
Current strategy of maintenance, time based/CBM/MIXED				
Explain the reason:				
Typical kind of failure mode found on the pumps:				
> Pump				
> Motor				
How is monitoring the information, manual/automatic				
Scope of work in each maintenance over haul				
Technology for CBM				
> Installed by manufacturer				
> Installed after some time in operation				
Type of sensor/technology to monitor LNG pump:				
> Vibration				
> Current				
> Process data				
> Other				
Trademark of sensor for vibrations				
Number and location of accelerometers used for each LNG pump				
Rack model installed				
What information is the sensor providing:				
> Velocity				
> Acceleration				
How is information send to control room:				
Wire/fiber optic/wireless				
Is your system in compliance with API 670 (Y/N)?				
What is the protection levels from the monitoring system:				
> Alarm/warning/trip				

Performance of the LNG pump monitoring system				
General performance of the vibration monitoring system: GOOD, REGULAR, BAD				
If regular or bad performance, reason for this: failure of the sensor/technology				
Root causes (i.e. Failure Mode & Effect Analysis, FMEA)				

Management of information				
Who perform the analysis:				
> In house: technician/engineer				
> Service provider: technician/engineer				
If service provider, how are they giving the support:				
> On line				
> On site, frequency				

Experience with predictive maintenance				
Is the experience GOOD/REGULAR/BAD?				
Explain the reason				
Has the utilization of CBM lead to longer maintenance period of LNG pump? YES/NO				
If no, why?				
If yes, why?, how long?				

LNG HIGH PRESSURE PUMPS

GIIGNL: Technical Study Group
Predictive Maintenance Benchmarking Group

HIGH PRESSURE PUMP QUESTIONNAIRE
Please, add additional columns if needed.
If needed for any celd, add the comments aparts.

Company:	
Terminal:	

Basic information of LNG pump				
	1	*2*	*3*	*4*
Trademark of LNG pump				
Model of LNG pump				
Number of pumps				
Design Pressure (barg)				
Flow rate (m3/h)				
Power (kW)				
Type start up (soft/direct)				
How long on operation (year of start up)				
Design MTBM (vendor recommendation)				
MTBM: max, aveg, min				
MTBF: max, aveg, min				
Number of Start/stop, frequency				
Running hours/year				

MTBM: Mean Time Between Maintenance
MTBF: Mean Time Between Failure

Specific information on CBM				
Current strategy of maintenance, time based/CBM/MIXED				
Explain the reason:				
Typical kind of failure mode found on the pumps:				
> Pump				
> Motor				
How is monitoring the information, manual/automatic				
Scope of work in each maintenance over haul				
Technology for CBM				
> Installed by manufacturer				
> Installed after some time in operation				
Type of sensor/technology to monitor LNG pump:				
> Vibration				
> Current				
> Process data				
> Other				
Trademark of sensor for vibrations				
Number and location of accelerometers used for each LNG pump				
Rack model installed				
What information is the sensor providing:				
> Velocity				
> Acceleration				
How is information send to control room:				
Wire/fiber optic/wireless				
Is your system in compliance with API 670 (Y/N)?				
What is the protection levels from the monitoring system:				
> Alarm/warning/trip				
Is there any software to analyze the information (Y/N)?				
How is the condition monitoring information used/processed, i.e., vibration spectrum,...				

Performance of the LNG pump monitoring system				
General performance of the vibration monitoring system: GOOD, REGULAR, BAD				
If regular or bad performance, reason for this: failure of the sensor/technology				
Root causes (i.e. Failure Mode & Effect Analysis, FMEA)				

Management of information				
Who perform the analysis:				
> In house: technician/engineer				
> Service provider: technician/engineer				
If service provider, how are they giving the support:				
> On line				
> On site, frequency				

Experience with predictive maintenance				
Is the experience GOOD/REGULAR/BAD?				
Explain the reason				
Has the utilization of CBM lead to longer maintenance period of LNG pump? YES/NO				
If no, why?				
If yes, why?, how long?				

BOIL-OFF GAS COMPRESSOR

GIIGNL: Technical Study Group
Predictive Maintenance Benchmarking Group

BOIL OFF COMPRESSOR QUESTIONNAIRE
Please, add additional columns if needed.
If needed for any celd, add the comments aparts.

Company:	
Terminal:	

Basic information of BOG Compressor				
	1	*2*	*3*	*4*
Type of compressor				
> Alternative vertical				
>Alternative horizontal				
> Other				
Parts monitored				
Technology used for each part				
Scope of work in each maintenance over haul				
Typical failure mode found on the compressor				
> Compressor				
> Motor				

Appendix 2 : Questionnaire 2

GIIGNL
Technical Study Group

PREDICTIVE MAINTENANCE BENCHMARKING GROUP
(document PMB/09/15)

This document shown a series of questions and tables in order to fulfil the gaps in the information **on LNG pumps** detected during the presentation of the initial questionnaire results, in the meeting held in Marseille (F) last 5th November 2009.

Please, fulfil the different tables and answer the questions. If necessary, you can write any additional explanation at the end of each page or adding more pages (properly labelled).

Finally, if you have any doubt about or question about this questionnaire, contact:
José A. Lana
Enagás, S.A.
jalana@enagas.es
Tel.: +34 976 469 826/822
Fax: +34 976 349 398

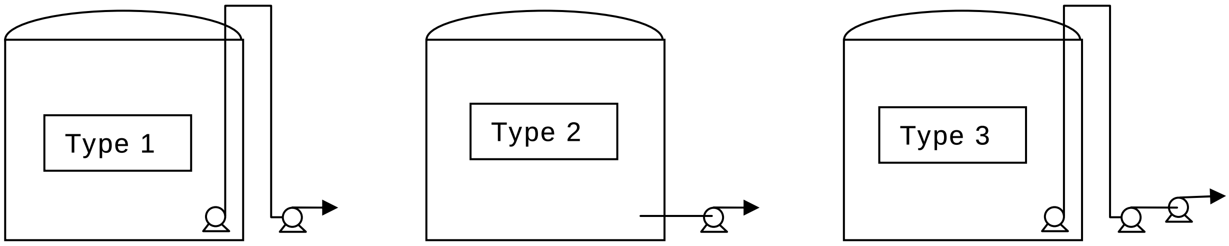
PLEASE, RETURN THE QUESTIONNAIRE BEFORE 20th JANUARY 2010

Document answer by: **COMPANY AND TERMINAL**

In order to clarify any doubt, contact to: **NAME**

Question 1

DISPOSITION OF LOW & HIGH PRESSURE PUMPS IN YOUR TERMINAL



COMPANY / TERMINAL	TYPE	MODEL OF PUMP	NUMBER OF PUMPS

Add additional rows if needed.

Comments:

Question 2

COMPONENTS OF VIBRATION DETECTION SYSTEM

Any CBM system relaying on the measurement of vibration is composed of several components. This components can be all supplied by the CBM system manufacturer or pump vendor or can be bought independently each other by the terminal operator.

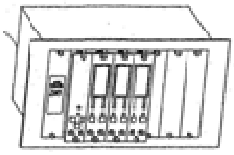
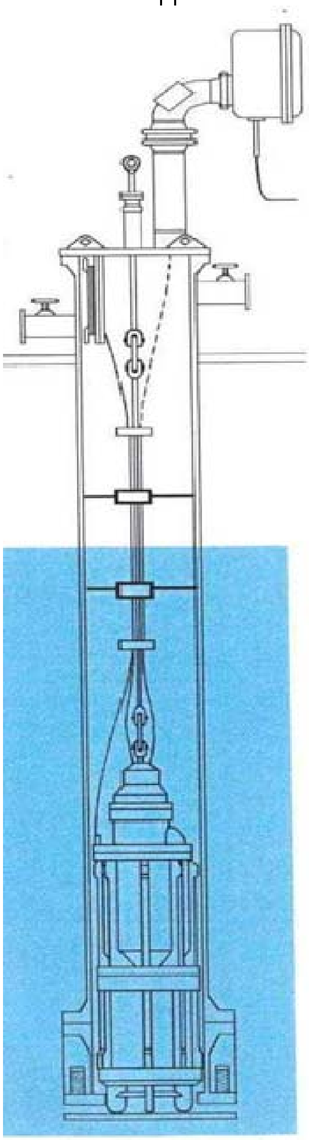
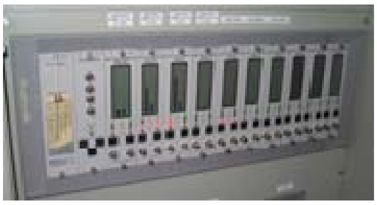
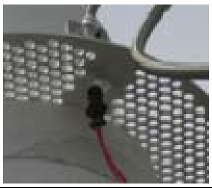
The CBM system has the following main parts:

- Sensor: accelerometer.
- Cryogenic cable between the sensor and the connector.
- Connector: it can be used to joint several cables from different sensors.
- Amplifier: to indicate if any amplifier is used.
- Cable: to connect the junction box/boxes and the rack.
- Rack: to analyse the signal/information received.

Please, inform about the brand of the different components and the supplier (CBM/pump vendor or other), trying to follow the example of one of our terminals (delete the info included).

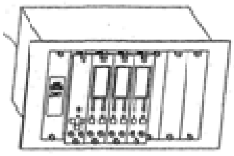
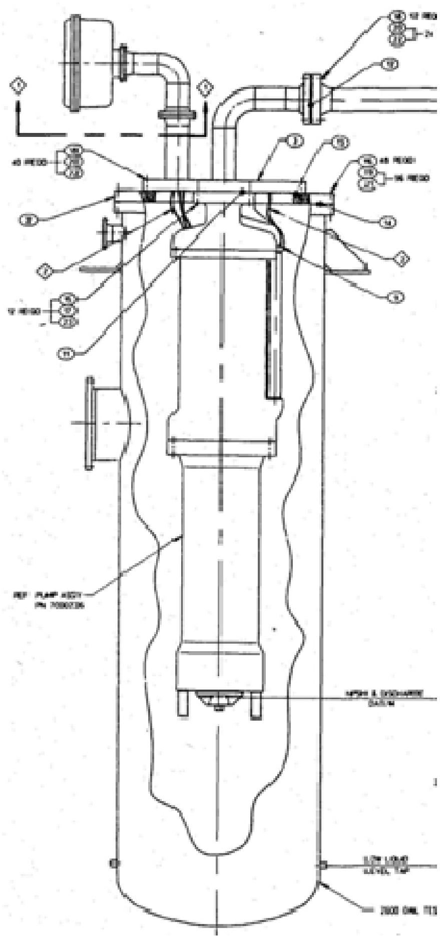
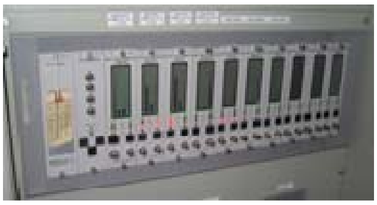
Add as much pages as needed (properly labelled).

LOW (IN TANK) PRESSURE PUMP

	COMPONENT	*BRAND (if applicable)*
 **Connected to rack** ⇑ 	RACK 	
	Type of wire between junction box and rack: Twisted pair Optical Fibber Other	
	AMPLIFIER 	
	CONNECTORS 	
	CRYOGENIC CABLE 	
	ACCELEROMETER 	

Comments:

HIGH (OUT OF TANK) PRESSURE PUMP

	COMPONENT	*BRAND (if applicable)*
 **Connected to rack** 	RACK 	
	Type of wire between junction box and rack: Twisted pair Optical Fibber Other	
	AMPLIFIER 	
	CONNECTORS 	
	CRYOGENIC CABLE 	
	ACCELEROMETER 	

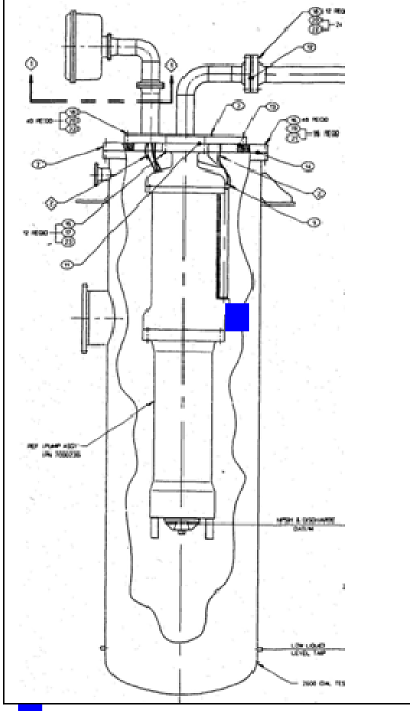
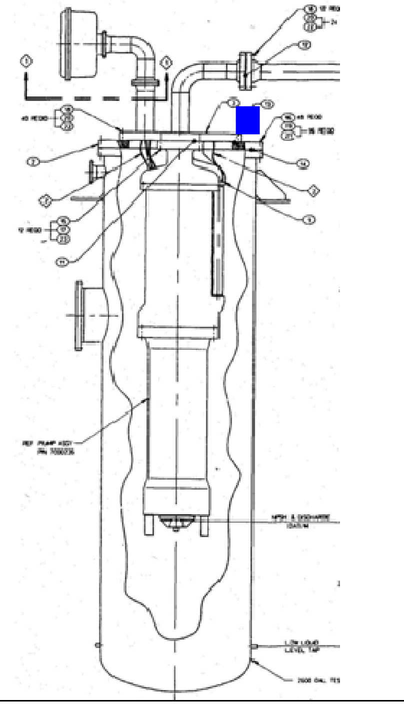
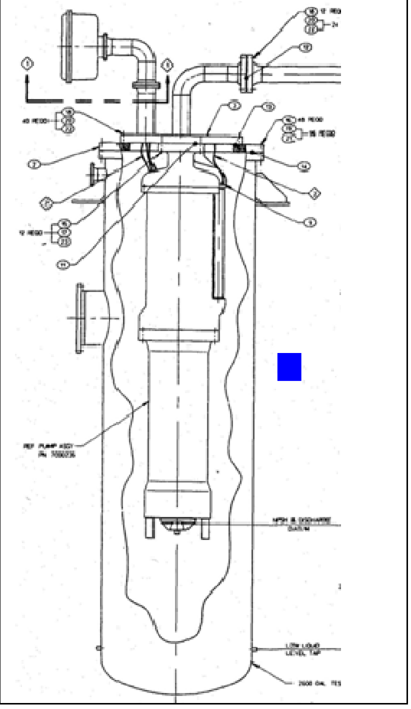
Comments:

Question 3

POSITION OF ACCELEROMETER

Three possible position for the accelerometer have been identified:
- Directly attached to the pump.
- Attached to the pump flange.
- Installed indirectly, i.e., attach to the pump can/pot.

If you are using several position or any other, please indicate.

Directly attached to the pump	*Attached to the flange*	*Indirectly, to pump can/pot*
Explain if needed.	Explain if needed.	Explain if needed.
		

■: sensor

Comments (if any):

Question 4

MEANING OF CBM / MIXED / TBM

In the analysis of the questionnaires, the maintenance strategy has been defined by the different participants as CBM or MIXED or TBM. As a result of the meeting in Marseille, it seems that this does not mean the same for each company, please choose from the definition list the most suitable for the CMB (if any) used in your terminal:

CBM: Condition Based Maintenance strategy. The maintenance of the pump is purely on condition, it means., the pump is maintained working until the vibration detector or any other parameter controlled gives an alarm level. Stop of the pump can be automatic or not.

MIXED. The pump is working until a predefined number of hours. The CMB system is mainly used for checking that everything is working right in the meantime, it means, any parameter is above the alarm level.

TBM: *Time Based Maintenance*. The pump is working until a predefined number of hours. If a CBM system is installed, this is not used at all due to any reason, i.e., lack of confident in it.

If needed, include any additional explanation.

Question 5

MAINTENANCE OF LNG PUMP

A.- Steps of maintenance of a pump during overhaul includes:

1st – Disassembled the pump.

2nd – Measured of tolerances of wear rings, bushing, rotor alignment, …, and visual inspection of diffuser, impeller and other internal parts.

3rd – Assembled of the pump:
- Internal components no fulfilling tolerance are changed by new ones.
- To install new bearings.
- To balance rotor.
- Other (please specify):

If any company is doing something different or additional, please specify.

B.- Spare parts:
Indicate if they are original pieces (from pump manufacturer) or from an alternative supplier (in this case, please mentioning if possible):
- Bearings
- Wear rings
- Bushing
- Diffuser
- Other:

Comment (if any):

Appendix 3: Boil-Off Gas Compressor questionnaire

GIIGNL: Technical Study Group
Predictive Maintenance Benchmarking Group

BOIL OFF COMPRESSOR QUESTIONNAIRE
Please, add additional columns if needed.
If needed for any celd, add the comments aparts.

Company:	
Terminal:	

Basic information of BOG Compressor				
	1	2	3	4
Supplier				
Type of compressor:				
> Alternative vertical				
> Alternative horizontal				
> Other (to specify: "Centrifugal")				
Capacity (Kg/h)				
Have you back-up capacity over nominal? (to specify)				
Regulation System:				
> By-Pass				
> Discharge Valves (Steps of Load)				
> Ramp (Hydrocom or similar)				
> Other (to specify)				
Main Maintenance Strategy:				
> Preventive:				
> Scope of work				
> MTBM				
> Predictive (MTBF)				
> Other (to specify)				
Parts monitored and Technology used				
> P-V diagrams (technology)				
> Vibrations (technology):				
> On cilinder				
> On crosshead				
> On frame				
> Rod-drop (technology)				
> temperature (technology)				
> Other (to specify)				
> Have you a continuos monitoring control system? (yes - supplier/not)				
Typical failure mode:				
> Compressor				
> Rider rings and segments				
> Valves				
> Nut looses				
> Other (to specify)				
> Motor (to specify)				

Appendix 4 : LNG pump CBM based on electrical measurement

Fluxys LNG and Enagas are (at the time of writing this report) testing a system base on electrical measurement in the LNG pump motor, as an alternative monitoring system for CBM, to determine the mechanical condition of the pump and its motor.

The electrical measurement (voltage and current) monitors are intelligent condition-monitoring devices which monitor three phase AC motors of all sizes and power levels to provide clear and unambiguous indications when the performance of a particular motor (or even the machinery it is connected to) begins to degrade, this should allow to substitute several traditional measurement devices for only one equipment, as shown in Figure A4.1.

Each monitor system uses three current sensors and, according to application, three voltage sensors (Figure A4.2).

The monitor units are networked to a workstation running an special software where they can all be viewed together. The software collects and manages information from all the monitor units, provides enhanced diagnostic capability, and allows remote operation of the complete system.

The control computer connects to the monitor units via an Ethernet. The arrangements for connecting the monitor units to the drive and to the computer is shown Figure A4.3

Specific software (features depending on the supplier) analyses the measurement and gives the information on the pump and motor condition.

Figure A4.1.- Measurement philosophy change.

Figure A4.2.- Current sensors.

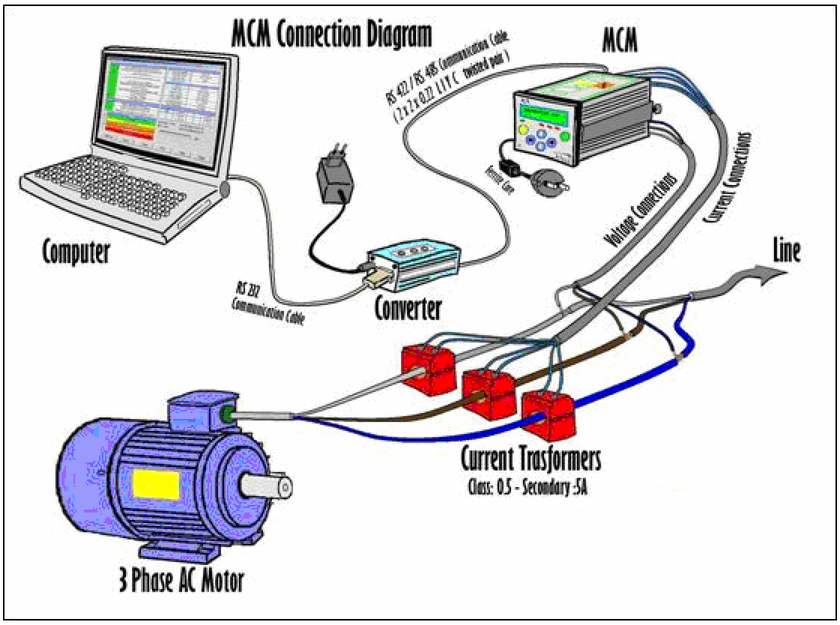


Figure A4.3.- System overview.

Appendix 5: List of document produced by the PMB Group

2009:

PBM/09/01 Scope of Work, revision 1.
PBM/09/02 Basic Data Sheet
PBM/09/03 Agenda and Schedule of meeting on 26th May 2009, Madrid, Spain.
PBM/09/04 Minutes of meeting on 26th May 2009, Madrid, Spain.
PBM/09/05 Scope of Work, revision 2.
PBM/09/06 Questionnaire, revision 1.
PBM/09/07 Questionnaire Answers at 1st October 2009.
PMB/09/08 Agenda Web Conference 16th October 2009.
PBM/09/09 Questionnaire Summary at 1st October 2009.
PBM/09/10 Questionnaire Answers at 30th October 2009.
PMB/09/11 Agenda and Schedule of meeting on 5th November 2009, Marseille, France.
PBM/09/12 Questionnaire Summary at 5th November 2009.
PBM/09/13 Minutes of meeting on 5th November 2009, Marseille, France.
PMB/09/14 Questionnaire on BOG compressor.
PMB/09/15 Additional questions, 10th December 2010.

2010:

PMB/10/01 Agenda and Schedule of meeting on 25th February 2010, Madrid, Spain.
PMB/10/02 Questionnaire 2 Summary on 22nd February 2010.
PMB/10/03 Slides presented by Enagas at meeting on 25th February 2010.
PMB/10/04 Presentation of Tokyo Gas at meeting on 25th February 2010.
PMB/10/05 Presentation of Osaka Gas at meeting on 25th February 2010.
PMB/10/06 Minutes of meeting on 25th February 2010, Madrid, Spain.
PMB/10/07 Agenda and Schedule of meeting on 13th May 2010, Camogli, Italy.
PMB/10/08 Report V 0.1 on PMB activities. Draft 1.
PMB/10/09 Presentation of GNL Italia at meeting on 13th May 2010.
PMB/10/10 Presentation of Enagas on BOG compressors at meeting on 13th May 2010.
PMB/10/11 Minutes of meeting on 13th May 2010, Camogli, Italy.
PMB/10/12 Report V 0.2 on PMB activities. Draft 2. 4th June 2010.
PMB/10/13 Questionnaire 2 on BOG compressor.
PMB/10/14 Report V 0.3 on PMB activities. Final for TSG comments. 27th July 2010.

2011:

PMB/11/01 Report V 0.4 on PMB activities. Final for TSG final comments. 10th January 2011.
PMB/11/02 Final Report on PMB activities, V 1.0. 20th December 2011.
PMB/11/03 Executive Summary of Final Report. 20th December 2011.