Study of SPM monitoring improvement

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ABSTRACT: The tanker FSO Leonis is moored near the offshore platform Vega A, to a steel column with circular section, 130 meters high and 10 meters in diameter. The system is installed in 1988 in the Sicilian Channel, and the connection is via a bridge structure with welded steel sections that make up the system SPM (Single Point Mooring). The structural system in steel box girders and column, with its cylindrical hinges, is calls-to the actions of the sea that induce cyclic stresses and fatigue. The paper presents a study on a possible improvement of the monitoring system installed in the structures that connecting the ship to the column, the monitoring, installed in October 2009, is composed of strain gauges sensors, in fiber optic and inclinometers. The research concerns the method of collecting and interpreting statistical data, to determine the structural behavior under the action of the wind and sea. Through the elaboration of monitored data it is possible to identify the dynamic response of the system SPM, counting the stress and number of fatigue cycles and conduct the verification in welded sections of steel box girders (yoke), column and the hinge joints. The results allowed us to evaluate the design assumptions and define a program of inspection and maintenance of steel structures of the offshore SPM system.

1 INTRODUCTION

The ship Leonis is located in the VEGA field that is approximately 12 miles south of the southern coast of Sicily, off the coast of Pozzallo. The field includes the platform called VEGA-A for the exploitation of the oil field and a 110,000 ton floating deposit obtained from the transformation of the former oil tanker Leonis in FSO (Floating - Storage - Offloading). The float is moored at SPM (single point mooring) located about 1.5 miles from the platform and connected to it via pipelines. In Figure 1 the ship Leonis and the SPM (column and yoke) are shown.

Figure 1. VEGA field, ship Leonis and the mooring system.

2 SPM 'S MONITORING SYSTEM

The VEGA-A platform and the tanker ship Leonis are monitored; the platform by means of 9 linear accelerometers, a current meter, a depth gauge, a microwave wave-meter and sensors for detecting speed and direction of wind. The SPM monitoring is constituted by a series of optical strain gauges and installed on the ship (# 25 strain gauge sensors, Fiber Bragg Gratings (FBG)) and on the Yoke (# 12 strain gauge sensors, Fiber Bragg Gratings (FBG)). Two biaxial inclinometers were also installed on SPM (# 2x2 inclinometer sensors). Therefore both the monitoring system installed are able to reconstruct the actions of the sea states and the wind e the correlations with the strain in the element.

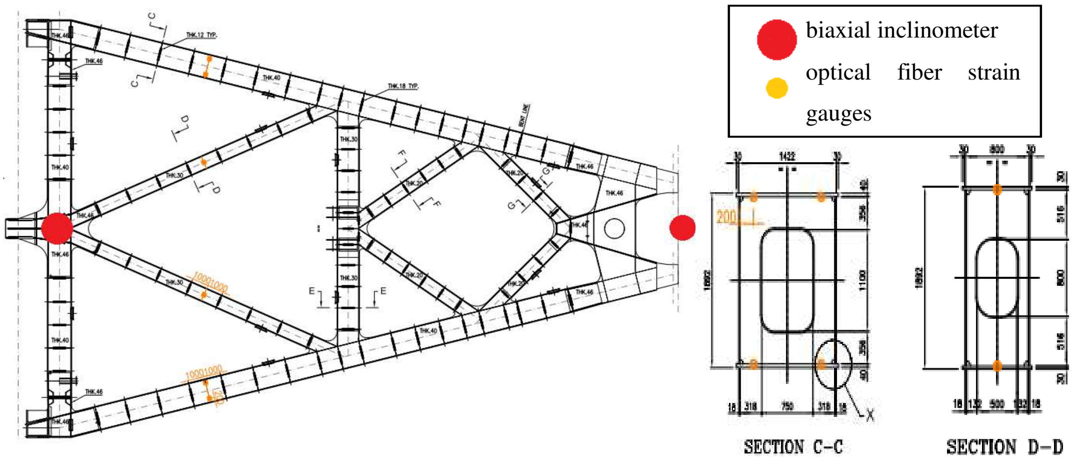

Figure 2. The SPM monitoring system.

In Figures 2 the location of sensors on the Yoke are shown. The time data acquisition for stress is 60 minutes with a sampling frequency f_c=0.5 Hz, while tilt angles are recorded with a sampling frequency f_c=1 Hz. The direction of the ship is recorded by hand by the Captain of Leonis. The conditions of sea and wind conditions are available by the monitoring system on the platform. FBG sensors are a multiplexed strain and temperature monitoring system based on Fiber Bragg Gratings. The multiplexed acquisition system of the optical strain gauges is composed of a control unit that acquires through 16 channels the signals from the sensors; the sensors are installed both on the ship that yoke (63 sensors, strain and temperature). The figures 3 and 5 shows the graph of some yoke's spectrum signals (channels # 13-14).

A possible improvement of the acquisition system can be to eliminate from the control unit the sensors installed on the ship (which currently do not work properly due to the interference with the elements of the ship tanks) and use the control unit only for the 25 sensors intended for the yoke. In this way, without changing the control unit, it will be possible to increase the sampling frequency of the strain gauges.

In the next sections we will be analyzed the data made available by the monitoring system. In particular we can see how it is possible to perform a dynamic identification system, reconstruct the actions value on the yoke caissons, reconstruct the overall values of the action that is transmitted to the column and the ship. In addition, through the analysis of these it will be possible to perform a fatigue analysis of any connected component. Finally, through the use of only the data of inclinometers we can perform a structural health analysis.

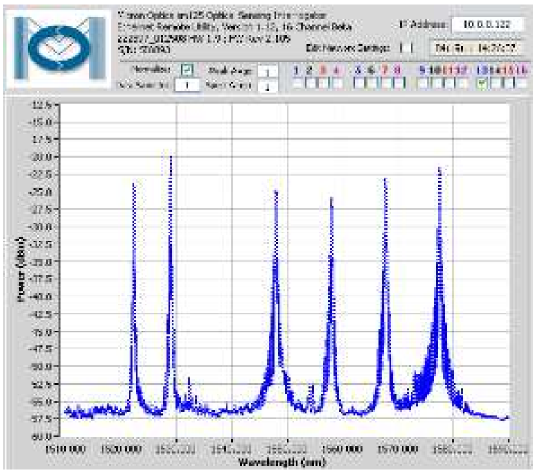

Figure 3. Spectra Control unit channel #13

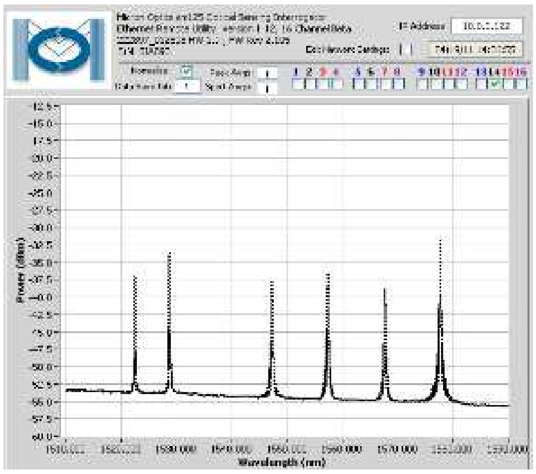

Figure 4. Control unit channel #14

3 ANALYSIS OF THE STRAIN DATA

In Table 1, are summarized the main features of the two main sea storm in 2016. The first with 5.12 m of height significant while the second with 4.78 m. The data have been acquired by means of the monitoring system installed on VEGA platform.

Table 1. Characteristics of the sea states (from monitoring system on VEGA platform)

day: h	H_s(m)	H_{max}(m)	T_z(s)	T_s(s)	T_{hmax}(s)	D_{seas}(°)	V_{wind}(m/s)	D_{wind}(°)
2016/03/04:03	5.12	9.66	8.26	9.29	9.37	268	15.32	316
2016/11/09:14	4.78	7.47	7.63	8.50	9.33	24	20.79	299

In the wide monitored sections (C-C) are placed 6 sensors: 4 bound to the structure (strain sensors) in the 4 vertices of the structural section, and 2 non-bound to the structure (temperature sensors) that are found in the mid-lower and the mid-top position.

The conversion and compensation of the raw data λ (bound data) and λ_T (non-bound data) in data strain takes place according to procedure illustrated in the job of Rizzo, Spadaccini, Castelli (2016).
Below, for example we report the compensated stress data and the inclinometers data for the sea storm of 2016/03/04, h03.

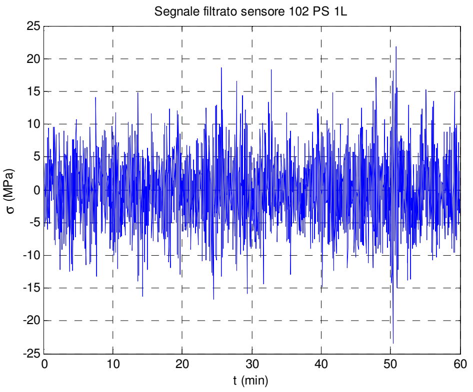

Figure 5. Stress data, sea state of 2016/03/04, h03.

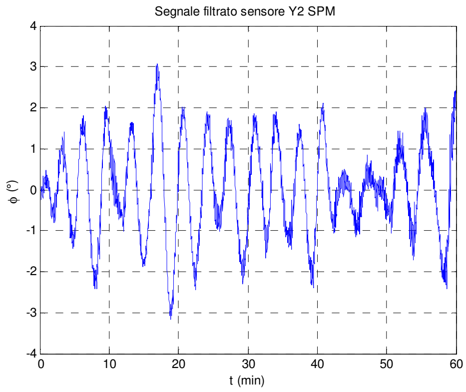

Figure 6. Inclinometer data, sea state of 2016/03/04, h03.

Through the data of the strain gauges and the inclinometers it is possible to perform a frequency analysis and obtain the spectra.

4 ANALYSIS OF THE GLOBAL ACTIONS

To compare the design strength of SPM system with the forces that are generated by the storms, the procedure presented in the job of Castelli , Rizzo , Spadaccini (2015), for reconstruction of global actions on column. The actions on the column were obtained using the 4 axial forces on the members of the yoke, mediating the forces on the 4 strain gauges, then the actions were obtained using the 4 forces and decomposing them according to the relative position of the column-yoke systems.

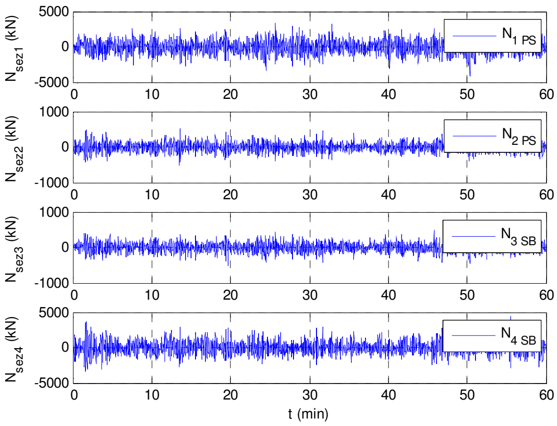

Figure 7. Time history of the axial action on the yoke's frames, storm of 2016/03/04, h03.

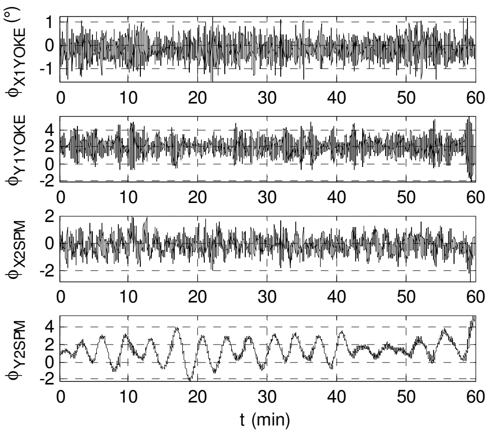

Figure 8. Inclinometer data, sea state of 2016/03/04, h03.

In Figure 7 we can see the axial action on the yoke's frames obtained for the storm of 2016/03/04 with H_s=5.12 m (see Table 1) while in Figure 8 the position (tilt values) of Yoke and Column during the event. In Figure 9 are shown the position of the system during the storm.

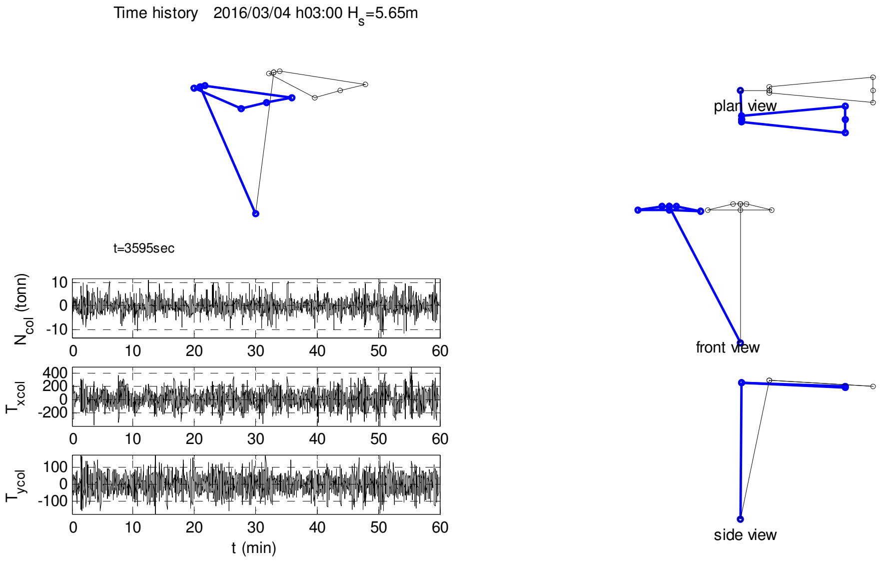

Figure 9. Time history inclinometers and position of the system, storm of 2016/03/04, h03.

In Figure 10 the actions on the column are shown. The extreme values, relating to storm of 2013/03/04, are lower than the design ones and assume the following values: N = 13 t, Tx=491 t and Ty =173 t.

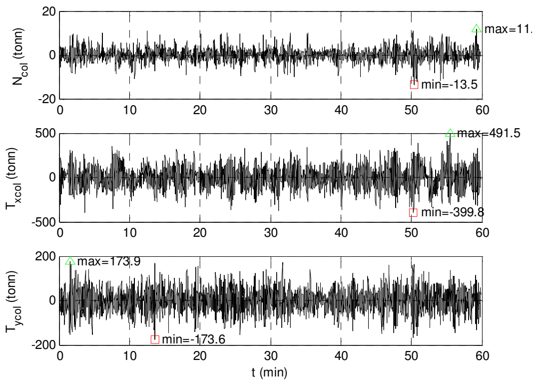

Figure 10. Action on the column, Tx, Ty, N, storm of 2016/03/04, h03.

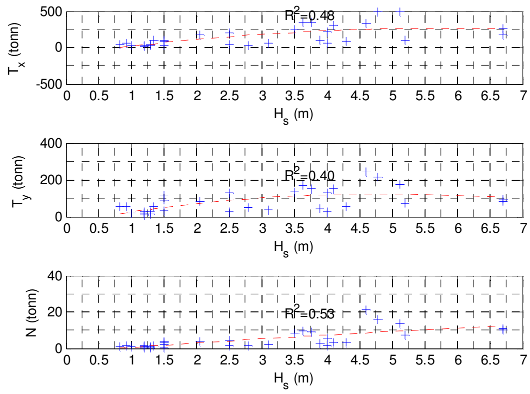

Figure 11. Action on the column, Tx, Ty, N vs Hs. - - quadratic trend line.

Finally we report in Figure 11 a wider analysis with waves of a increasing intensity. The analyzes show the evolution of the forces on the column as a function of the significant wave height.

5 FATIGUE ANALYSIS

The fatigue analysis was performed using measurement results. The rainflow method of Matsuishi and Endo (1968) and the Palmgren-Miner rules are used for evaluation of fatigue damage. The fatigue analysis is performed for the most loaded node using the WAFO toolbox for Matlab. The toolbox contains routines for statistical analysis of the random stress function, as well as modules for performing a rainflow counting and calculating the damage accumulation according to the Palmgren-Miner rule. The routines can be used to extract the rainflow cycles from the stress time function.

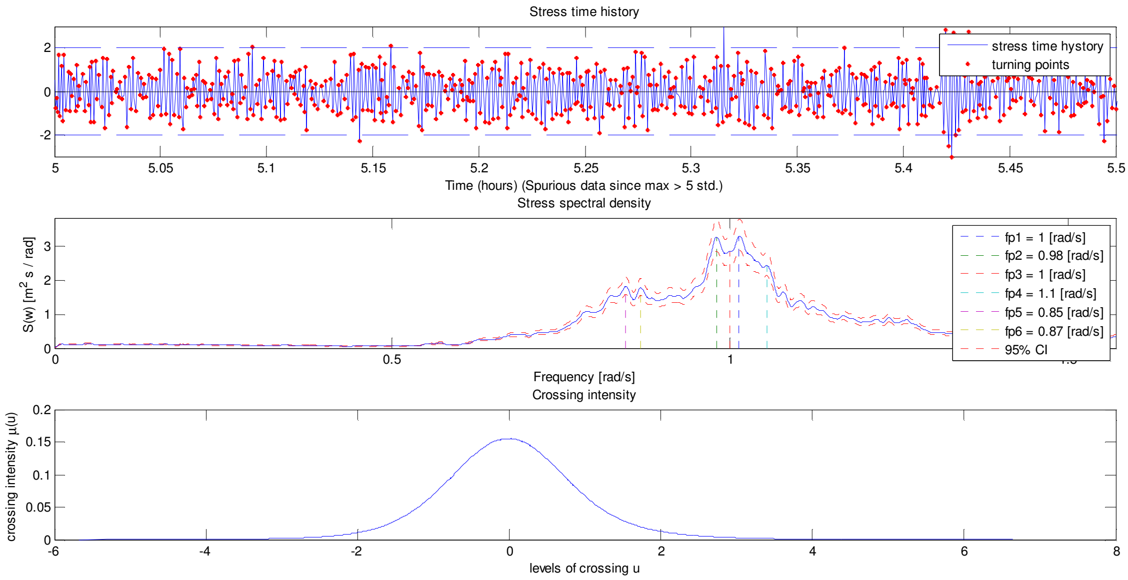

Figure 12. Time history of the response; Stress time history, spectral density and crossing intensity, storm of 2014/03/04, hour 03.

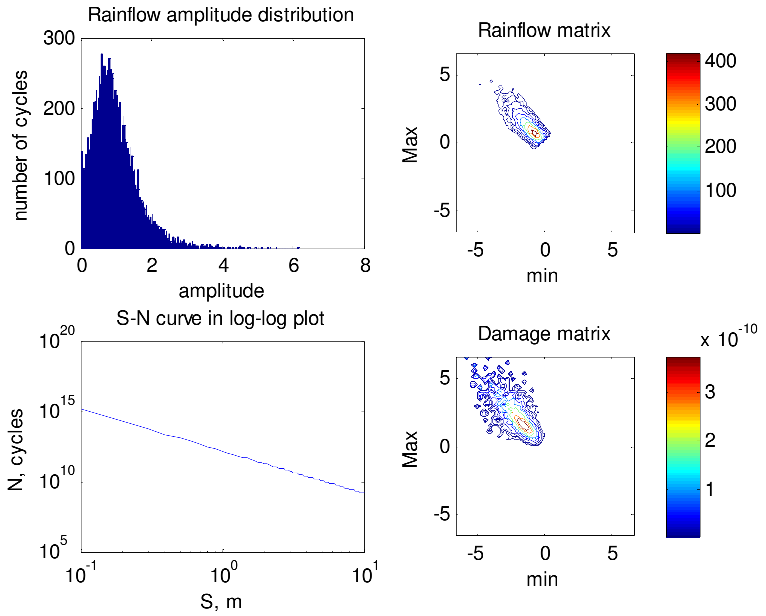

Figure 13. Rainflow amplitude distribution, rainflow matrix, S-N curves and damage matrix, storm of 2014/03/04, hour 03.

From the sequence of turning points the number of min-max cycles and the rainflow cycles can be estimated. The min-max cycles give the number of the observed transitions from a local minimum to a local maximum. Rainflow amplitude distribution, rainflow matrix, S-N curves and damage matrix, storm of 2016/03/04 are shown in Figure 12. The model S-N curve for steel welded connection with the parameters by DNV (2011), Table 2.1 S-N curve type T, m=3 and K = 1.45881E+12 is used in fatigue damage calculation. The S-N curve is presented in Figure 13 in logarithmic plot. The stress history can be represented as an stress amplitude histogram against number of rainflow cycles in Fig.13. In Figure 14 are reported the fatigue spectra and the fatigue life, increasing the number of days for the winter 2013.

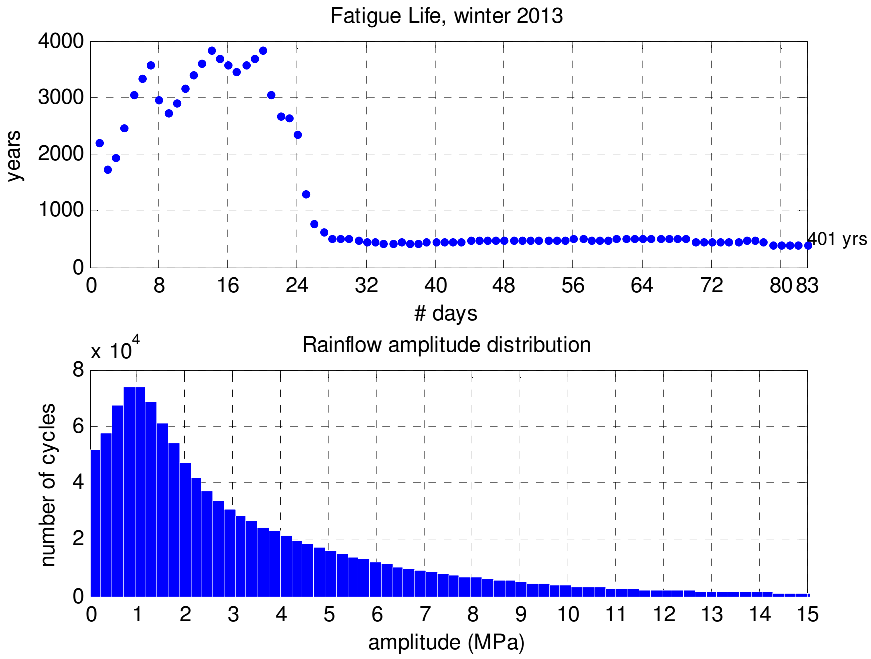

Figure 14. Fatigue analysis by increasing the days of winter 2013.

6 MONITORING AND DAMAGE: SHM

The Structural Health Monitoring (SHM) relies on the repeated observation of damage-sensitive features such as natural frequencies. The problem is that changes in temperature, relative humidity, operational loading, and so on also influence those features. This influence is in general nonlinear and also nonlinear is the system SPM-Yoke-Vessel. In this work, the technique based on kernel principal component analysis, improved by Reynders et al., (2014) and modified by Rizzo, Spadaccini, Castelli (2016).

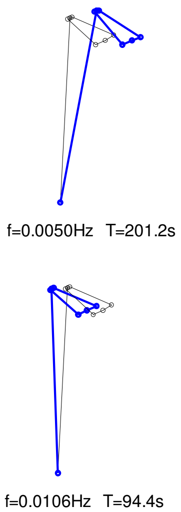

Figure 15. Identified mode shapes of mooring system.

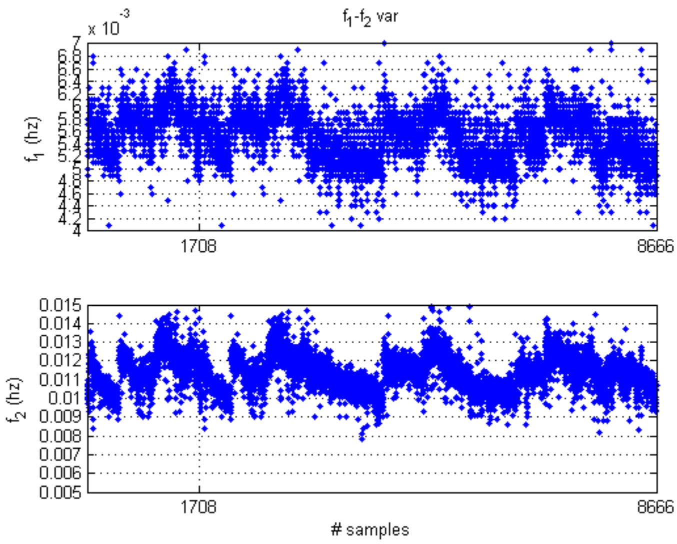

Figure 16. Frequency trend January 2014-December 2016.

The analysis shows that it is possible to identify two mode shapes of rigid motion, for this analysis, each distinguished by the frequencies f_1 and f_2; the first mode shape is characterized by a transversal motion (relative to the axis joining the yoke and the ship), while the second by a transverse motion.

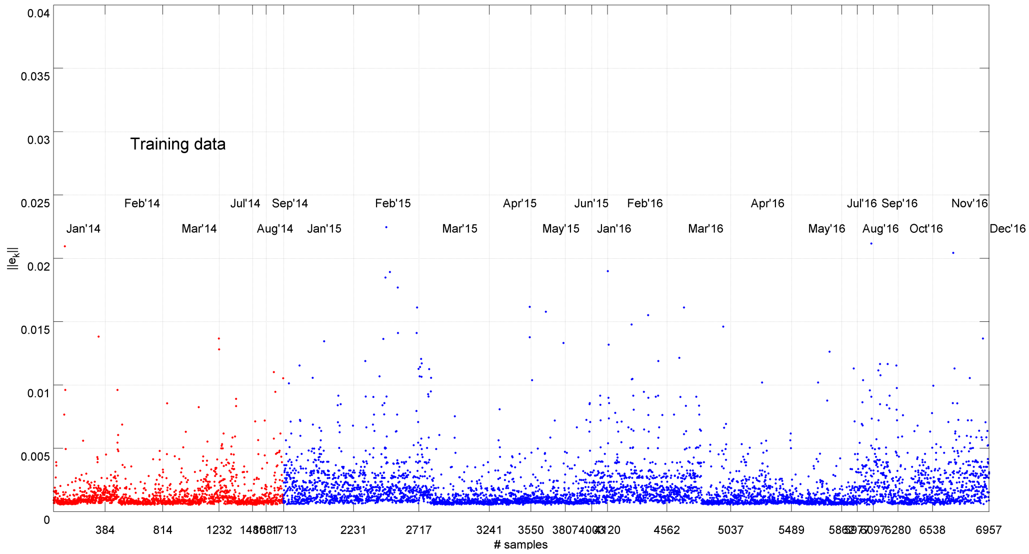

Figure 17. Misfit of the nonlinear output-only model constructed with training data Year 2014.

An extended analysis of the system, targeted to identify the first two fundamental frequencies in the years 2014 and 2016 led to the results shown in Figure 16. We can see from the graphs that the trend is ups and downs for both frequencies f_1 and f_2. This behavior is due to the fact that the vessel (tanker) is filled with oil until flushed. The effect on the frequency is clear, the increased mass causes a reduction in frequencies. The ship is unloaded approximately every three months and change in frequencies is a prominent feature of this oscillating system. The trend of misfit indicates that significant damage to the system has not happened during the reporting period, in spite of what can be deduced from observation 'not aware' by the trend of frequencies in the same period shown in Fig. 16.

Conclusions

The present work shows the characteristics of the monitoring system installed in the SPM in the VEGA field. The monitoring system makes possible to reconstruct the global actions on the column in order to compare these values with the project ones. The results of the monitoring system are a valuable tool for identify the structural response, the fatigue during the life of the SPM and a useful support in the risk based inspections.

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