Monitoring Possibility of Sailing Ships' Masts

L. MURAWSKI, W. OSTACHOWICZ, M. MIELOSZYK
and K. MAJEWSKA

ABSTRACT

Marine structures like: marine vessels, submarines and offshore structures surrounded by a harsh marine environment are exposed to long-term cyclic loadings comes from continuously acting sea waves and short-term extreme loads such as severe storms, seaquakes or even collisions. The marine environment (sea water) results in fast corrosion, erosion and scour processes. Those phenomena increase the size of an existing damage and also initiate its growth. Any damage of a marine structure can results in endanger human life, ecologic and economical catastrophe.

The idea of the marine SHM is to build a system that is able to evaluate a condition of a monitoring structure in different environmental and exploitation conditions. One of the most promising sensors for that purpose is those based on fibre optics technology, especially Fibre Bragg Grating (FBG) sensors. FBG sensors can be successfully used for static and dynamic measurements. Recognition of practical application possibilities of fibre optic experimental techniques based on FBG sensors in the SHM of sailing ships' masts is our aim. Practical implementation of safety system based on optical sensors meets several difficulties. In the paper monitoring system of the foremast of scholar ship - frigate "Dar Mlodziezy", is presented. Research on STS Dar Mlodziezy was carried out during nine days voyage at Baltic Sea. Research was related to characteristics of Dar Mlodziezy's foremast during her normal operation. The main goal of this research was to determine the size of stress/strain of foremast above topmast crosstrees where three steel jib stays are mounted. To achieved this goal, during this research special attention was paid to setting the sails and taking in the sails. In the SHM system FBG strain, temperature and two kinds of piezoelectric acceleration sensors have been used. During SHM system designing FBG sensors are verified and compared with classical deformation sensors and electrical strain gauges. Stability, sensitivity and error bounds of FBG strain sensors have been determined in different marine environmental conditions. The piezoelectric acceleration sensors are used for ship movements (e.g. yawing) recording. Typical piezoelectric sensors have been compared with seismic type accelerometers.

Institute of Fluid-Flow Machinery PAS-ci in Gdansk, Poland/ Department of Mechanics of Intelligent Structures

INTRODUCTION

Structural Health Monitoring (SHM) with damage detection techniques became more and more important from economical, human safety and environment protection point of view. SHM systems are widely adapted in the wide range of civil engineering [1], offshore structures, aviation as well as automotives, ships, wind turbines etc. Safety of ships is very important but practical implementation of experimental techniques meets several difficulties in marine conditions.

Recognition of practical application possibilities of fibre optic experimental techniques in the marine SHM is our aim. Precise determination of characteristics for two different measurement techniques (classical and based on fibre optic) has been the main aim of the investigations. Stability, sensitivity and error bounds of Fiber Bragg Grating (FBG) strain sensors were analyzed. Also their ability for damage detection has been also our target.

FBG sensors are gaining increasing attention in the field of experimental strain/stress analysis [2]. Fiber–optic sensors are one of the most prominent technologies that have successfully migrated from the laboratory to the field applications [3]. The main benefits of fiber optic (in particular FBG sensors) have been found in their long–term stability and reliability as well as in their insensitivity to the external perturbations like electromagnetic fields. These techniques have significant advantages in comparison to more conventional sensors, especially for structural health monitoring [4]. Researches of the fibre optic sensors applicability and monitoring system design should be still leaded. Also, data collection, analysis and interpretation need developing [5].

The authors present a first step of structural health monitoring system project dedicated to marine structures - the foremast of scholar ship - frigate "Dar Mlodziezy" (Fig. 1). The system is based on fibre optic technique with Fibre Bragg Grating (FBG) sensors.

Figure 1. Frigate "Dar Mlodziezy".

ANALYSIS OF MEASUREMENT RESULTS OF THE FOREMAST OF THE STS DAR MLODZIEZY

During the research FBG sensors system and system of piezoelectric accelerometers (three seismic sensors and one three-directional classical sensor) was used. FBG system was mounted on the foremast (Fig. 2). Accelerometers system was mounted in navigator's room. The optical system consist of seven FBG sensors (type os3120 Epoxy Mount from Micron Optics – 22mm long) - four dedicated for strain measurements and one dedicated for temperature compensation. FBG sensors grid placed on foremast (35-meter fibre optic cable) was connected with FBG interrogator SmartScan 04 (from Smart Fibre, Bracknell, UK) placed in navigator's room on upper deck. Each sensor obviously has its own Bragg wavelength. The FBG sensors were divided into two lines.

Figure 2. Foremast of STS Dar Mlodziezy with marked FBG sensors location.

Results obtained from FBG and accelerometers sensors were analysed. Accelerometers sensors were designed for recorded the motion of the hull on sea waves. During the analysis the motion of the ship was assumed as a rigid body motion. During all measurements the sea state was vary from 1 to 4 in the Beaufort scale. The frequencies of rolling of the ship vary from 0.20 Hz to 0.28 Hz, which corresponds to the period of oscillations from 3.5 s to 5 s. An example of frequency of the hull motion measured at the base of the foremast is presented in Fig. 3. The frequencies above 10 Hz recorded during tests are associated with vibrations forced of on-board equipment and environmental conditions.

Starting the analysis of obtained results, the so called "zero drift" was determined - the stress values in every sensor for the case when the mast was theoretically unloaded (the ship was in port). The level of the average stress values obtained for the case mentioned above is presented in Fig. 4. The following notation is applied in the whole article: sensor No. 2 (sig_2, k2) is located in vertical position in plane symmetry of ship; sensor No. 3 (sig_3, k3) – horizontal in PS; sensor No. 4 (sig_2, k4) – vertical in

PS ~1 m above sensor No. 2; sensor No. 5 (sig_5, k5) – vertical transverse to PS; sensor No. 1 (sig_t, kt) – temperature compensation. During all analysis the temperature compensation was taken into consideration. The stress changes (0.5 MPa) occur in the foremast even in the absence of loads from the sails and the ship motion. This is mainly due to the changes in ambient temperature. A temperature compensation sensor eliminates thermal strains of FBG of the mast without causing its loads. However, temperature changes affect the strains of ship rigging (stays, shrouds), which already affects the actual loads of masts.

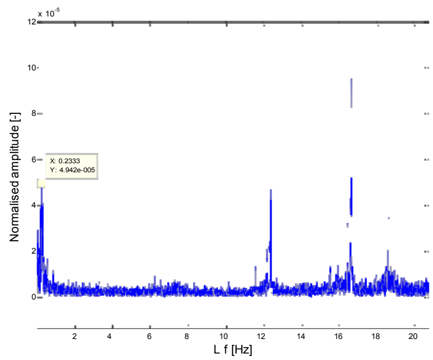

Figure 3. Ship vibrations at the base of the foremast.

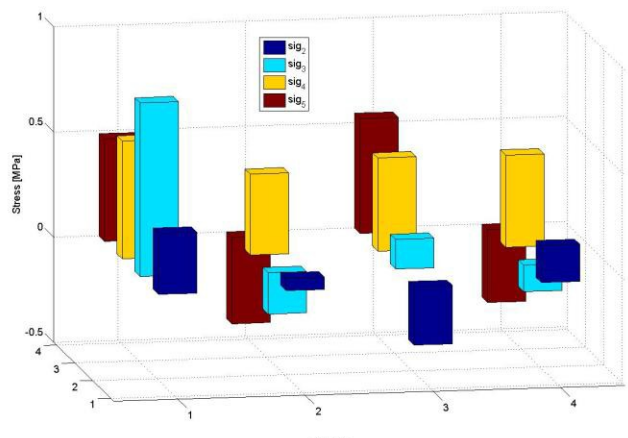

Figure 4. The stress changes of unloaded foremast.

The load changes of the foremast for different operating conditions were checked. The mean values of stress changes for the ship without sails (Test No.1), with all sails at wind speed equal to 3 m/s (Test No.2) next for course, lower and upper topsail at wind speed equal to 8 m/s (Test No.3 and Test No.4) is shown in Fig. 5. Last two tests were carried out twice to check repeatability of measurements. As it is clearly shown the stability and repeatability of the proposed SHM system is very good. The stress changes of foremast as a function of time for steady state sailing conditions (Test No.3 and Test No.4) are presented in Fig. 6 - where an oscillation in load changes of foremast is clearly visible. Dynamic analysis of load changes of the foremast is presented in Fig. 7. All sensors show the same characteristic of dynamic changes - which is about 5 s. A period of changes is approximately equal to undulation of the sea for steady state sailing conditions and stays in good correlation with indication of acceleration sensors (see Fig. 3). Forecasting the strength of masts the dynamic loading and fatigue resistance should be taken into account.

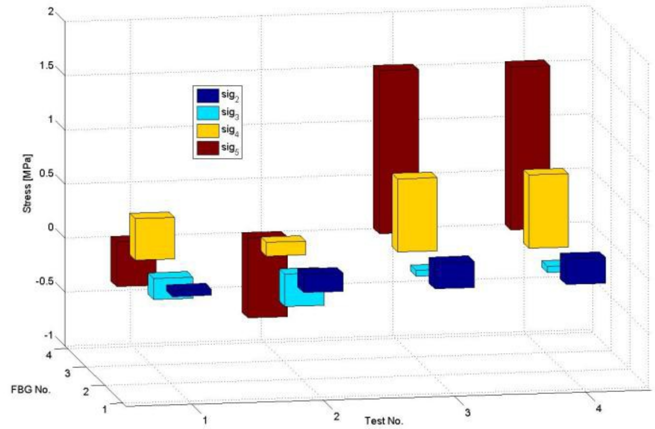

Figure 5. The load changes of foremast for steady state sailing conditions.

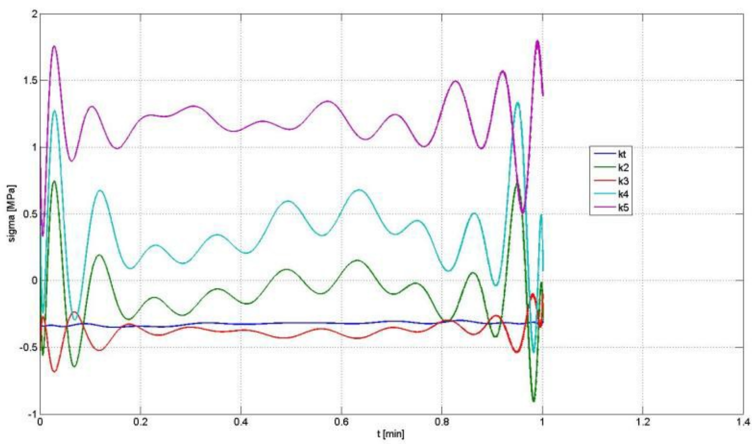

Figure 6. Interpolated stresses in a time function for steady state sailing conditions.

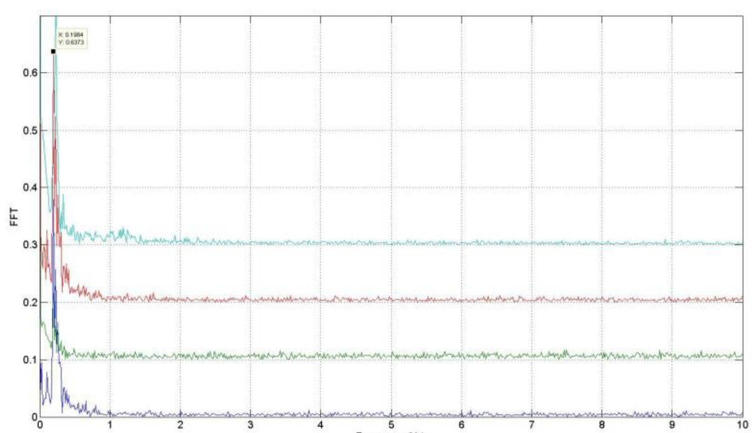

Figure 7. Dynamic analysis of load changes of the foremast.

Stress changes in foremast during setting sails and manoeuvres of the ship are presented in Fig. 8. The study was conducted by short (few seconds) independent measurements. Each measurement was averaged and presented as a bar chart. During the measurements wind speed was equal to 9.75 m/s, and sea state was 3 in Beaufort's scale, maximum speed of the ship was 9 knots. The sequence of every measurement was as follow: Test No.1 - drift without sails; Test No.2 - setting the fore mast staysail; Test No.3 - setting the inner jib; Test No.4 - setting the outer jib; Test No.5 - setting the flying jib; Test No.6 - setting the lower topsail; Test No.7 - setting the upper topsail; Test No.8 - setting the topgallant; Test No.9 - setting the royal; Test No.10 - setting the course; Test No.11 - taking in the royal; Test No.12 - taking in the course; Test No.13 – wearing; Test No.14 - setting the course; Test No.15 – bracing; Test No.16 - steady state sailing. Wearing, and even the bracing causes significantly greater increase in stresses (observed in transverse direction to symmetry plane of the ship) than setting the sails. Stress level observed in transverse direction to symmetry plane of the ship may increase up to twice during changing the direction of relative wind. In the same time stress level observed in symmetry plane of the ship is relatively small. The ship sailing speed has strong influence on the stress level of masts. Taking in the fore course and keeping other sails significantly increase in loads observed in transverse direction to symmetry plane of the ship. Stresses observed in transverse direction to symmetry plane of the ship (sig 5) strongly depend on environmental conditions and quantity of sails. Bending of the foremast in symmetry plane of the ship (sig 2, sig 4) strongly depend on quantity of sails. Setting the headsails reduce the loads of upper part of the foremast in symmetry plane of the ship. Dynamic analysis, type FFT, characteristic for setting the sails is shown in Fig. 9 - Test No. 9. The foremast with setting the lower topsail, upper topsail and topgallant is sensitive for changing load. Loads associated with waves (period about 6.5 s) as well as transverse vibration of the foremast with frequency equal to 1.26 Hz which can be associated with the frequency of natural vibration of the mast is clearly visible.

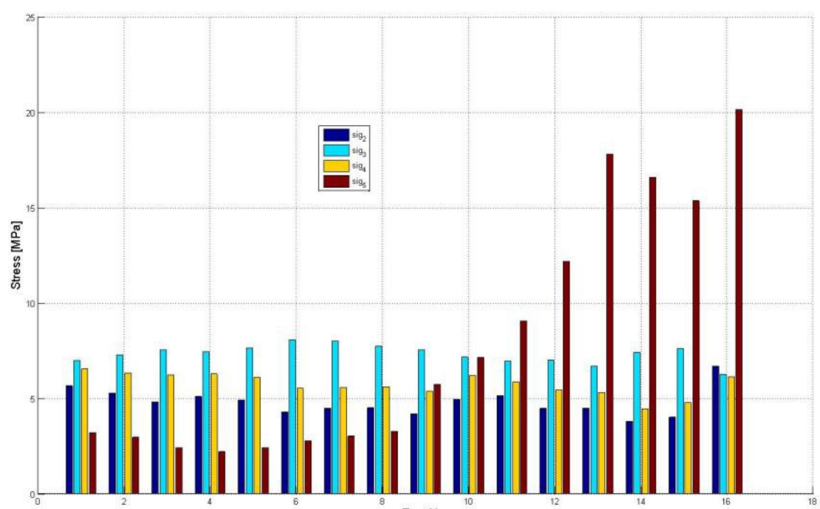

Figure 8. Load changes during setting the sails and maneuvers of the ship.

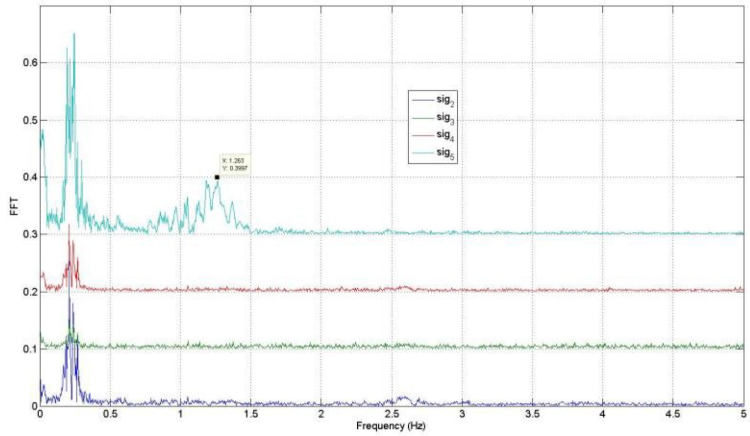

Figure 9. Frequency analysis of load changes of the foremast.

CONCLUSIONS

The main benefits of fiber optic have been found in their long–term stability and reliability as well as in their insensitivity to the external perturbations like electromagnetic fields. The investigations reported in this paper have shown big potential of fibre-optic Bragg grating sensors for SHM systems dedicated for marine and offshore structures.

ACKNOWLEDGEMENTS

The authors of this work would like to gratefully acknowledge the support for this research provided by the Polish Ministry of Science and Higher Education through the European Funds System under the Sectoral Operational Programme Improvement of the Competitiveness of Enterprises via MONIT project (Monitoring of Technical State of Construction and Evaluation of Its Lifespan) nr POIG.01.01.02-00-013/08.

REFERENCES

1. Li, H.N., D.S. Li and G.B. Song. Recent applications of fiber optic sensors to health monitoring in civil engineering, Engineering Structures 26:1647–1657, 2004.
2. Kreuzer, M. Strain measurement with Fiber Bragg Grating sensors, HBM, Darmstadt, 2009.
3. Glisic, B. and D. Inaudi. Fiber Optic Methods for Structural Health Monitoring, John Wiley & Sons, Hoboken, West Suessex, 2007.
4. Udd, E. Fiber Optic Sensors: An Introduction for Engineers and Scientists, John Wiley & Sons, New Jersey, 2006.
5. Farrar, C.R., K. Worden, M.D. Todd, G. Park, J. Nichols, D.E. Adams, M.T. Bement, and K. Farinholt. Nonlinear System Identification for Damage Detection, Los Alamos National Laboratory report no. LA-14353, 2007.