A METHOD FOR CONTINUOUS-TIME IDENTIFICATION OF MOORED SYSTEMS

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***Abstract*— In this paper a method for continuous-time identification for the class of moored semisubmersible marine systems based on totally measured states is presented. The exponential convergence of parameter trajectories is analyzed in the context of conditions for persistency of excitation (PE). A regression for the estimator is constructed containing generically 312 parameters to be identified. The presented analysis has revealed that the regressor must expand a space of only 24 dimensions instead of 312 for unbiased estimates. Under monochromatic excitation, PE conditions are expected to be satisfied only in chaotic behaviors. A case study of a real moored crane-platform is modelled and simulated to verify such conditions.**

***Keywords*— Nonlinear Semisubmersible Dynamics, Moored Systems, Identification, Identifiability, Persistency of Excitation.**

I. INTRODUCTION

The increasingly growing complexity in ocean operations and design of marine structures and vehicles, imposes the necessity of modern methods and tools for stability analysis and control tasks. An important exponent of these systems constitutes the class of moored semisubmersible structures (platforms, barges, tanks, buoys, among others), which are set up for operations in harbors and offshore.

Moored marine structures are often characterized by transitions from linear to nonlinear behaviors under certain wave conditions, which make the operation to become unpredictable (Kreuzer, 1993; Dmitrieva and Lougovsky, 1997). In extreme cases such a nonlinear response can turn into chaos and may cause the floating structure to capsize. From practical viewpoints, small and large chaotic oscillations or subharmonics have to be avoided and controlled in order to attain safe and foreseen operations. On the other hand, they constitute one way to provide a good excitation for parameter estimation. In other words, bifurcations are undesired in the behaviour (and so control is requested) but beneficial for identification. As many physical parameter are slowly varying in time, control actions have to be intended in an adaptive way. The design of a generic adaptive law and its analysis for a case study is the chief matter in this paper.

A semisubmersible can be considered as a multibody system composed by subsystems interacting each one with the rest, *e.g.*, platform, mooring lines and load. The excitation sources result from waves, wind and currents. Physical parameters of interest are wave height, frequency, wave number, platform and load masses, active lengths of catenaries among others.

The use of modern tools for stability analysis, like Lyapunov coefficient diagrams and bifurcation theory, requires a detailed analytical model of the system, what in turns means, a precise knowledge of the physical parameters and model structure. Related with them are the hydrodynamic coefficients which are of pure mathematical provenience, but they play an important role in the determination of bifurcations (Kreuzer *et al.*, 2002).

The hydrodynamics of a semisubmersible is based on the Potential Theory for diffraction and reflection of waves. These methods use finite elements for computing the efforts of the fluid interaction with wet parts of the platform and are available in commercial programs. Usually, the results of the stability analysis have to be confronted with experimental results carried out in laboratories with reduced-scale models at relative high costs.

An alternative to the use of dedicated programs is developed in this work. It consists of parameter identification based on measured signals of the behavior, e.g., gyroscopic and cinematic states. This has the advantage that it can be performed on-line with a small amount of a-priori information. The algorithm can adapt automatically for changes of the mass, the operation points and changes of the environment if a forgetting factor or similar procedure is incorporated as in the classic form. Thus, stability analysis and controller design can obtain this information on-line and directly from on-board instrumentation.

The main objective in this paper is devoted to the design a method for parameter estimation of physical coefficients and to the study of convergence conditions. In the first part, the model structure of an offshore floating structure with mooring lines is constructed attending all forces that are present in the dynamics. By means of dedicated programs, the response is simulated for several parameters that leads to bifurcations. In the second part, an estimator is designed to accomplish the true model structure. The estimator is shown to be able to converge exponentially under unperturbed measures if certain conditions for the excitation an states are fulfilled. The necessary and sufficient conditions for persistency of excitation are also analyzed.

II. DYNAMICS REPRESENTATION

The dynamics of a semisubmersible is characterized by six degrees of freedom, namely, the surge η_1, the sway η_2, the heave η_3, the roll η_4, the pitch η_5 and the yaw η_6. It is represented by (Schelin *et al.*, 1993)

$$M(\eta)\ddot{\eta} + K(\eta, \dot{\eta}) = F, \tag{1}$$

with $\eta = [\eta_1, \eta_2, \eta_3, \eta_4, \eta_5, \eta_6]^T$ the state vector, M the inertia matrix of the system, K the generalized gyroscopic forces and F the generalized forces.

The inertia matrix of the system is

$$M = \begin{bmatrix} m & 0 & 0 & 0 & m\eta_{3G} & -m\eta_{2G} \\ 0 & m & 0 & -m\eta_{3G} & 0 & m\,\eta_{1G} \\ 0 & 0 & m & m\eta_{2G} & -m\eta_{1G} & 0 \\ 0 & -m\eta_{3G} & m\eta_{2G} & I_{\eta_1\eta_1} & 0 & -I_{\eta_1\eta_3} \\ m\eta_{3G} & 0 & -m\eta_{1G} & 0 & I_{\eta_2\eta_2} & 0 \\ -m\eta_{2G} & m\eta_{1G} & 0 & -I_{\eta_1\eta_3} & 0 & I_{\eta_3\eta_3} \end{bmatrix}, \tag{2}$$

where m is the mass of the body and equal to the displaced water, η_{iG} are the coordinates of the center of gravity and I_{kj} corresponds to the mass moments of inertia

$$I_{\eta_1\eta_1} = \int_m (\eta_2^2 + \eta_3^2) dm \tag{3}$$

$$I_{\eta_2\eta_2} = \int_m (\eta_1^2 + \eta_3^2) dm \tag{4}$$

$$I_{\eta_3\eta_3} = \int_m (\eta_1^2 + \eta_2^2) dm \tag{5}$$

$$I_{\eta_1\eta_3} = \int_m \eta_1\eta_3\, dm. \tag{6}$$

The generalized forces represent external time-varying forces and they result from the superposition of the six effects, i.e.,

$$F = F_G + F_B + F_V + F_M + F_\omega + F_I, \tag{7}$$

where the subscript G corresponds to gravity, B to hydrostatic buoyancy, V to viscous drag, M to mooring lines, ω to incident waves and I to hydrodynamics of the ideal fluid response.

The gravity force is given by

$$F_G = \begin{bmatrix} 0 \\ 0 \\ mg \\ mg(\eta_{1G}\,\eta_6 + \eta_{2G} - \eta_{3G}\,\eta_4) \\ -mg(\eta_{1G} - \eta_{2G}\,\eta_6 + \eta_{3G}\,\eta_5) \\ 0 \end{bmatrix}, \tag{8}$$

where g is the gravity constant.

The hydrostatic force containing buoyancy effects has the expression

$$F_B = \begin{bmatrix} 0 \\ 0 \\ -mg - \rho g A_w \eta_3 \\ -mg\overline{OM}_T\eta_4 \\ -mg\overline{OM}_L\eta_3 \\ 0 \end{bmatrix}, \tag{9}$$

where ρ is the water density, A_w the ship water-plane area, $\overline{OM}_T$ and $\overline{OM}_L$ the longitudinal and transverse metacentric heights, respectively.

The viscous drag force for each degree of freedom is represented by

$$F_{Vj} = -\frac{1}{2}\rho C_{Dj} A_{Ej} \left|\dot{\eta}_j\right| \dot{\eta}_j, \tag{10}$$

with $j = 1, ..., 6$, C_{D_j} an empirical drag coefficient and A_{Ej} a proportionality constant dependent on the geometry of the wet part.

The nonlinear restoring forces of the mooring lines are

$$F_{Mj} = -C_{lj}\eta_j - C_{qj}\left|\eta_j\right|\eta_j - C_{cj}\eta_j^3, \tag{11}$$

with $j = 1, ..., 6$ and C_{lj}, C_{qj} and C_{cj} are restoring force coefficients.

The incident wave forces are approximated by

$$F_\omega = F_\omega^{(1)} + F_\omega^{(2)}, \tag{12}$$

where $F_\omega^{(1)}$ is the so-called first-order wave force and $F_\omega^{(2)}$ is the second-order drift force (Kreuzer *et al.*, 2002).

The hydrodynamics results from the interaction between structure and fluid. See Schelin *et al.* (1993) for more details. The resulting hydrodynamic force is calculated as

$$F_I = -a(\infty)\,\ddot{\eta} - b(\infty)\dot{\eta} + s_0, \tag{13}$$

where $a(\infty)$, $b(\infty)$ are the values of the so-called hydrodynamic added mass and damping at frequency infinity, respectively. The vector s_0 is originated from a state space model of six order

$$\dot{s}_{n-k} = s_{n+1-k} - A_k s_0 - B_k\dot{\eta}, \tag{14}$$

with s_k the state for $k = 0, 1, ..., 7$, $s_7 = 0$, A_k and B_k parameter matrices.

Consider again (1). The term $K(\eta, \dot{\eta})$ contains the effects of relative motion of the axes, i.e., gyroscopic, Coriolis and centrifugal forces. In considering instrumentation that is based on inertial measurements, all variables are referred to inertial axes. Thus

$$\frac{d}{dt}\begin{bmatrix} s_0 \\ s_1 \\ s_2 \\ s_3 \\ s_4 \\ s_5 \\ s_6 \\ \dot{\eta} \\ \eta \end{bmatrix} = \begin{bmatrix} s_1 - A_6 s_0 - B_6 \dot{\eta} \\ s_2 - A_5 s_0 - B_5 \dot{\eta} \\ s_3 - A_4 s_0 - B_4 \dot{\eta} \\ s_4 - A_3 s_0 - B_3 \dot{\eta} \\ s_5 - A_2 s_0 - B_2 \dot{\eta} \\ s_6 - A_1 s_0 - B_1 \dot{\eta} \\ -A_0 s_0 - B_0 \dot{\eta} \\ (M + a(\infty))^{-1}(F - F_I + s_0) \\ \dot{\eta} \end{bmatrix}. \tag{15}$$

III. PHYSICAL PARAMETER IDENTIFICATION

For identification of physical parameters it is supposed that the signals for dynamic positioning and the hydrodynamic states are measurable and noise-free. For the first group, this is entirely realistic using on-board sensors. For the hydrodynamic states an adaptive observation system has to be employed. To this goal some results of the adaptive observation for this problem are published in Jordán and Beltrán-Aguedo (2001).

Accordingly a regression model is proposed using the model given by (15). It is

$$y(t, \hat{\theta}) = \Phi^T(t)\, \hat{\theta}, \tag{16}$$

where $\Phi : [0, t] \to \Re^{m \times n_0}$ is the regressor matrix, $\hat{\theta} \in \Re^{n_0}$ is the parameter vector and $y : [0, t] \to \Re^{m \times 1}$ is the predicted state. In more details

$$\begin{aligned} y = \big[\; & (\dot{s}_{0_1} - s_{1_1}) \;\cdots\; (\dot{s}_{0_6} - s_{1_6}) \;\cdots \\ & (\dot{s}_{1_1} - s_{2_1}) \;\cdots\; (\dot{s}_{1_6} - s_{2_6}) \;\cdots \\ & \dot{s}_{6_1} \;\cdots\; \dot{s}_{6_6} \;\cdots \\ & (s_{0_1} + F_{w1}) \;...\; (s_{0_6} + F_{w6}) \;\big]^T, \end{aligned} \tag{17}$$

$$\Phi^T = \left[\begin{array}{ccccccc}
s_{0_1} & \cdots & s_{0_6} & 0 & \cdots & 0 & \cdots \\
0 & \cdots & 0 & s_{0_1} & \cdots & s_{0_6} & \cdots \\
\vdots & \vdots & \vdots & \vdots & \ddots & \vdots & \cdots \\
0 & \cdots & 0 & 0 & \cdots & 0 & \cdots \\
0 & \cdots & 0 & 0 & \cdots & 0 & \cdots \\
0 & \cdots & 0 & 0 & \cdots & 0 & \cdots \\
0 & \cdots & 0 & 0 & \cdots & 0 & \cdots \\
0 & \cdots & 0 & 0 & \cdots & 0 & \cdots \\
\dot{\eta}_1 & \cdots & \dot{\eta}_6 & 0 & \cdots & 0 & \cdots \\
0 & \cdots & 0 & \dot{\eta}_1 & \cdots & \dot{\eta}_6 & \cdots \\
\vdots & \vdots & \vdots & \vdots & \ddots & \vdots & \cdots \\
0 & \cdots & 0 & 0 & \cdots & 0 & \cdots \\
0 & \cdots & 0 & 0 & \cdots & 0 & \cdots \\
0 & \cdots & 0 & 0 & \cdots & 0 & \cdots \\
0 & \cdots & 0 & 0 & \cdots & 0 & \cdots \\
0 & \cdots & 0 & 0 & \cdots & 0 & \cdots \\
0 & \cdots & 0 & 0 & \cdots & 0 & \cdots \\
0 & \cdots & 0 & 0 & \cdots & 0 & \cdots \\
\vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \cdots \\
0 & \cdots & 0 & 0 & \cdots & 0 & \cdots \\
0 & \cdots & 0 & 0 & \cdots & 0 & \cdots \\
\ddot{\eta}_1 & \cdots & \ddot{\eta}_6 & 0 & \cdots & 0 & \cdots \\
\vdots & \cdots & 0 & \ddot{\eta}_1 & \cdots & \ddot{\eta}_6 & \cdots \\
0 & \cdots & 0 & 0 & \cdots & 0 & \cdots \\
0 & 0 & 0 & ... & 0 & 0 & \cdots \\
0 & 0 & 0 & ... & 0 & 0 & \cdots \\
\vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \cdots \\
0 & 0 & 0 & ... & 0 & 0 & \cdots \\
0 & 0 & 0 & ... & 0 & 0 & \cdots \\
|\dot{\eta}_1|\,\dot{\eta}_1 & 0 & 0 & \eta_1 & 0 & 0 & \cdots \\
\vdots & \ddots & \vdots & \vdots & \ddots & \vdots & \cdots \\
0 & 0 & |\dot{\eta}_6|\,\dot{\eta}_6 & 0 & 0 & \eta_6 & \cdots \\
0 & 0 & 0 & \cdots & 0 & 0 & \\
0 & 0 & 0 & \cdots & 0 & 0 & \\
\vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \\
0 & 0 & 0 & \cdots & 0 & 0 & \\
0 & 0 & 0 & \cdots & 0 & 0 & \\
|\eta_1|\,\eta_1 & 0 & 0 & \eta_1^3 & 0 & 0 & \\
\vdots & \ddots & \vdots & \vdots & \ddots & \vdots & \\
0 & 0 & |\eta_6|\,\eta_6 & 0 & 0 & \eta_6^3 &
\end{array}\right], \tag{18}$$

and

$$\begin{aligned} \hat{\theta} = \big[\; & A_{6_{11}} \;\cdots\; A_{6_{16}} \;\; A_{6_{21}} \;\cdots\; A_{6_{26}} \;\cdots \\ & A_{0_{11}} \;\cdots\; A_{0_{16}} \;\; A_{0_{21}} \;\cdots\; A_{0_{26}} \;\cdots \\ & B_{6_{11}} \;\cdots\; B_{6_{16}} \;\; B_{6_{21}} \;\cdots\; B_{6_{26}} \;\cdots \\ & B_{0_{11}} \;\cdots\; B_{0_{16}} \;\; B_{0_{21}} \;\cdots\; B_{0_{26}} \;\cdots \\ & m_{11} + a_{11}(\infty) \;\cdots\; m_{16} + a_{16}(\infty) \;\cdots \\ & m_{21} + a_{21}(\infty) \;\cdots\; m_{26} + a_{26}(\infty) \;\cdots \\ & C_{D_1} \;\cdots\; C_{D_6} \;\; C_{l_1} \;\cdots\; C_{l_6} \;\cdots \\ & C_{q_1} \;\cdots\; C_{q_6} \;\; C_{c_1} \;\cdots\; C_{c_6} \;\big]^T. \end{aligned} \tag{19}$$

The method of least-squares will be used for identification in continuous time. Least-squares estimates are obtained by minimizing the integral square error with respect to the parameter vector variable $\hat{\theta}$, that is

$$\min_{\hat{\theta} \in \Re^{n_0}} J(t, \hat{\theta}) = \frac{1}{2t} \int_0^t \left\| \varepsilon(\tau, \hat{\theta}) \right\|^2 d\tau, \tag{20}$$

where the estimation error is $\varepsilon(\tau) = y(\tau, \theta) - \hat{y}(\tau, \hat{\theta}) = y(\tau, \theta) - \Phi^T(t)\hat{\theta}(t)$, with θ the true parameter vector.

Differentiating J with respect to $\hat{\theta}$ one gets

$$\bigtriangledown J(t,\hat{\theta})=\frac{1}{t}\int_0^t \Phi(t)\left[y(t,\theta)\text{-}\Phi^T(t)\hat{\theta}(t)\right]d\tau \quad (21)$$

and

$$\left[\int_0^t \Phi(t)\Phi^T(t)d\tau\right]\hat{\theta}(t)=\int_0^t \Phi(t)y(t,\theta)d\tau. \quad (22)$$

Now, defining the estimator gain matrix as

$$P(t)=\left[\int_0^t \Phi(t)\Phi^T(t)d\tau\right]^{-1} \quad (23)$$

and differentiating $P^{-1}(t)$ with respect to the time and with $P(t)P^{-1}(t)=I$,

$$0=\frac{d}{dt}\left[P(t)\right]P^{-1}(t)+P(t)\frac{d}{dt}\left[P^{-1}(t)\right]. \quad (24)$$

Therefore

$$\dot{P}(t)=-P(t)\Phi(t)\Phi^T(t)P(t). \quad (25)$$

Now, differentiating (22) with respect to time and considering (23) it results

$$\dot{\hat{\theta}}(t)=-P(t)\Phi(t)\varepsilon(t). \quad (26)$$

The trajectory $\hat{\theta}(t)$ accomplishes $\underset{t\to\infty}{lim}\ \hat{\theta}(t)=\theta$.

A. Analysis of Persistency of Excitation

Consider again (20)

$$\begin{aligned}&\min_{\theta\in\Re^{n_0}} J(t,\hat{\theta})=\\&\frac{1}{2t}\sum_{i=1}^{n_0}\left(\hat{\theta}-\theta\right)^T\left(\int_0^t \phi_i(\tau)\phi_i^T(\tau)\,d\tau\right)\left(\hat{\theta}-\theta\right)=\\&\sum_{i=1}^{n_0}\frac{1}{2t}\int_0^t \varepsilon_i^2(\tau,\hat{\theta}_i)d\tau,\end{aligned} \quad (27)$$

where $\hat{\theta}^T=\left[\hat{\theta}_1^T,...,\hat{\theta}_i^T,...,\hat{\theta}_m^T\right]$, ϕ_i^T is a row of Φ and ε_i are components of ε. For achieving persistency of excitation every vector ϕ_i^T must fulfills

$$span\left(\phi_i^T\right)=\dim(\hat{\theta}_i),\ i=1,...,m,$$

where $\hat{\theta}_i\in\Re^{n_i}=\mathcal{D}_{\hat{\theta}_i}$ with $\mathcal{D}_{\hat{\theta}_1}\times...\times\mathcal{D}_{\hat{\theta}_i}\times...\times\mathcal{D}_{\hat{\theta}_m}=\Re^{n_0}$. It means, each regressor ϕ_i^T must contain sufficient harmonics (at least n_i) in order to span the subspace $\Re^{n_i}$. Thus, in ensuring the convergence of trajectories $\hat{\theta}(t)\subset\Re^{n_0}$, each regressor by itself must provide persistent excitation in its own subspace $\Re^{n_i}$.

For instance, consider the first regressor in (18)

$$\begin{aligned}\phi_1^T \;=\; [\; & s_{0_1}\ \ ...\ \ s_{0_6}\ \ 0\ \ ...\ \ 0\ ...\\ & \dot{\eta}_1\ \ ...\ \ \dot{\eta}_6\ \ 0\ \ ...\ \ 0\ ]^T.\end{aligned} \quad (28)$$

It contains 12 states, then it will be necessary a frequency content of at least 12 harmonics in order to ensure the convergence of $\hat{\theta}_1$ in (19) with

$$\hat{\theta}_1=\left[\ A_{6_{11}}\ \ ...\ \ A_{6_{16}}\ \ ...\ \ B_{6_{11}}\ \ ...\ \ B_{6_{16}}\ \right]^T. \quad (29)$$

The same occurs for the regressors ϕ_2^T up to ϕ_{42}^T, since they are obtained by shifting the components of ϕ_1^T to the right in the corresponding rows. They must fulfill the same previous condition of exciting persistency. Hence

$$\begin{aligned}&\text{if } span\left(\phi_1^T\right)=\Re^{12}\Rightarrow\text{partial parameter}\\&\text{convergence in }\mathcal{D}_{\hat{\theta}_1}\times...\times\mathcal{D}_{\hat{\theta}_{42}}\equiv\Re^{252}.\end{aligned}$$

The rest of the regressors, i.e., $\phi_{43}^T,...,\phi_{48}^T$, have a different structure with respect to the previous ones. They are composed by

$$\begin{aligned}\phi_{42+i}^T \;=\; [\; & \ddot{\eta}_1\ \ ...\ \ \ddot{\eta}_6\ \ 0\ \ ...\ \ 0\ ...\\ & |\dot{\eta}_i|\,\dot{\eta}_i\ \ \ \eta_i\ \ \ |\eta_i|\,\eta_i\ \ \ \eta_i^3\ \ 0\ ...\ \ 0\ ]^T.\end{aligned} \quad (30)$$

with $i=1,...,6$. One notices in (30) that at least 6 harmonics are needed for the subvector $\left[\ddot{\eta}_1,...,\ddot{\eta}_6\right]^T$ and additionally one more for the rest, it is for the subvector $\left[|\dot{\eta}_i|\,\dot{\eta}_i,\eta_i,|\eta_i|\,\eta_i,\eta_i^3\right]^T$. This is inferred from the following fact. If η_i contains one harmonic, the $|\dot{\eta}_i|\,\dot{\eta}_i$ results linearly independent of η_i. Besides, $|\eta_i|\,\eta_i$ and η_i^3 are also independent of η_i. Usually, for an arbitrary signal $\eta_i(t)$ the regressor $\left[\eta_i,|\eta_i|\,\eta_i,\eta_i^3\right]^T$ must fulfill

$$\begin{cases}\alpha_1\eta_i(t)+\alpha_2\,|\eta_i(t)|\,\eta_i(t)+\alpha_3\eta_i^3(t)\neq c_1\\ \alpha_1+2\alpha_2\,\text{sign}(\eta_i(t))\eta_i(t)+3\alpha_3\eta_i^2(t)\neq c_2\\ 2\alpha_2\,\text{sign}(\eta_i(t))+6\alpha_3\eta_i(t)\neq c_3,\end{cases} \quad (31)$$

where α_j and c_j are arbitrary real-valued constants.

Hence, at least 7 harmonics are required for every ϕ_{42+i}^T. Due to the fact that $\left[\ddot{\eta}_1,...,\ddot{\eta}_6\right]^T$ repeats in every ϕ_{42+i}^T, one concludes that at least 12 frequencies are needed for $\left[\phi_{43},...,\phi_{48}\right]^T$ in order to accomplish persistency of excitation. Thus

$$\begin{aligned}&\text{if } span\left(\left[\phi_{43},...,\phi_{48}\right]^T\right)=\\&span\left(\left[\ddot{\eta}_1,...,\ddot{\eta}_6,\eta_1,...,\eta_6\right]^T\right)=\Re^{12}\\&\Rightarrow\text{partial parameter convergence}\\&\text{in }\mathcal{D}_{\hat{\theta}_{43}}\times...\times\mathcal{D}_{\hat{\theta}_{48}}\equiv\Re^{60}.\end{aligned}$$

In summary,

$$\begin{aligned}&\text{if } span\left(\left[\phi_1,...,\phi_{48}\right]^T\right)=\Re^{24}\Rightarrow\\&\text{parameter convergence in }\Re^{n_0}\equiv\Re^{312}.\end{aligned}$$

It is worth noticing that only a few amount of different frequencies in comparison with the amount of parameters is required for achieving exponential parameter convergence.

B. Identifiability of Physical Parameters

According to (19) the coefficients $m_{ij} + a_{ij}(\infty) = \theta_{ij}$ are identified uniquely, so it is impossible to rescue m_{ij} and $a_{ij}(\infty)$ from $\hat{\theta}_{ij}$ separately. In order to attain identifiability of the physical parameters $a_{ij}(\infty)$, the values of the masses and inertia moments are required. These depend on geometry and mass distribution of the platform.

It is noticing that in stability analysis of the platform behavior the so-called hydrodynamic coefficients are required. These can be obtained from the identified physical parameters (19). The procedures to do this fall outside the scope of this paper.

IV. REAL-WORLD CASE STUDY

In order to show that the former conditions for persistency excitation are fulfilled for typical behaviours of the presented systems, a case study is analyzed. This concerns the crane platform DB102 (see Fig. 1). For technical details see Riekert (1992).

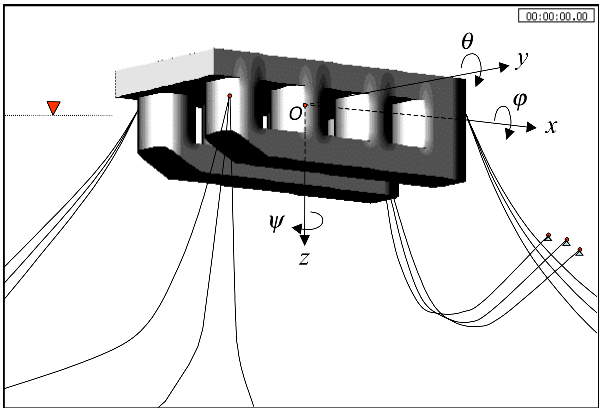

Figure 1: Moored crane ship THIALF (DB102)

The software $AQWA^{®}$ is used for modelling and simulation of the dynamics of the DB102. This program requires a complete geometrical description of the structure and computes the linearized hydrodynamic structure-fluid loading using 3-dimensional diffraction/radiation theory. The fluid is considered ideal and the incident wave acting on the body is assumed to be monochromatic and of small amplitude compared with its wavelength.

A series of experiments were set up for different values of the wave amplitude a and period T, and stiffness of the mooring lines C_l, C_q and C_c. These were taken as bifurcation parameters and changes of the qualitative dynamic behaviours were searched for.

Suitable parameters were found for period-2 ($a = 0.6\,[m]$, $T = 9.66\ [sec]$, $C_l = 50\ [N/m]$, $C_q = 0\ [N/m^2]$ and $C_c = 100\ [N/m^3]$) and chaos ($a = 0.02\,[m]$, $T = 1.5\ [sec]$, $C_l = 10000\ [N/m]$, $C_q = 0\,[N/m^2]$ and $C_c = 1000\ [N/m^3]$). The corresponding behaviours results of the states η_1 and η_3 are depicted in Figs. 2-5.

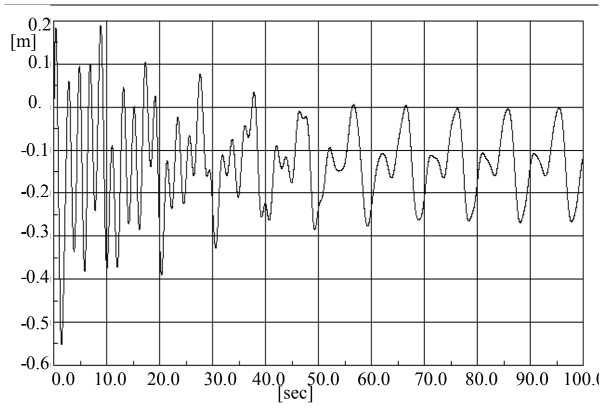

Figure 2: Behavior of the surge state η_1 in period-2

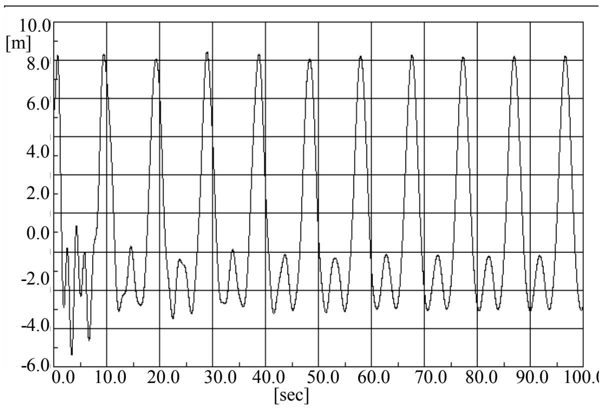

Figure 3: Behavior of the heave state η_3 in period-2

An analysis in the frequency domain of the behaviour can reveal that period-2 evolutions are insufficient to attain persistent of excitation in $\Re^{24}$. Consequently biased parameters would be obtained asymptotically even when a short transient response can be beneficial in the approximation phase. On the contrary, in the presented chaotic situation an appropriate frequency content is achieved satisfying the necessary and sufficient stationary conditions for persistent excitation. It is worth noticing that such a situation is unusual in operation of marine systems, but possible in real environments..

V. CONCLUSIONS

In this paper a method for continuous-time identification for the class of moored semisubmersible marine systems based on totally measured states is presented. The exponential convergence of parameter trajectories is analyzed in the context of conditions for persistency of excitation (PE). A regression for the es-

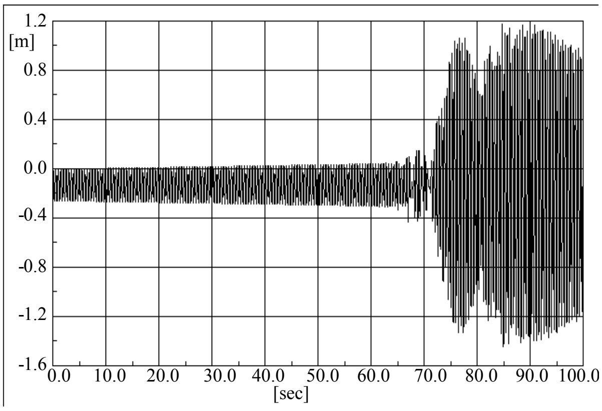

Figure 4: Behavior of the surge state η_1 in chaos

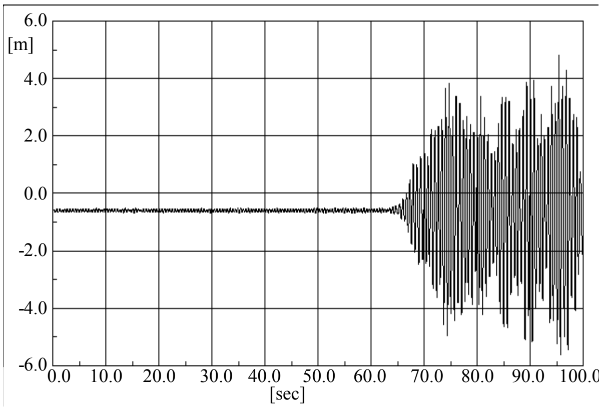

Figure 5: Behavior of the heave state η_3 in chaos

timator is constructed containing generically 312 parameters to be identified. The presented analysis has revealed that the regressor must expand a space of only 24 dimensions instead of 312 for unbiased estimates. Under monochromatic excitation, PE-conditions are expected to be satisfied only in chaotic behaviors. A case study of a real moored crane-platform is modelled and simulated to verify such conditions.

ACKNOWLEDGMENTS

The authors want to thank Professor Dr.-Ing. Edwin Kreuzer and Dr.-Ing. Volker Schlegel at Technical University of Hamburg-Harburg and the Technical University of Berlin for the theoretical support and test facilities. Dr.-Ing. Mario Jordán, thanks also CONICET and Scientific Cooperation Project with Germany (AL/A99 - EX II/17) for financial supporting of this investigation.

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