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Sliding Control Applied to Subsea Oil and Gas Separation System under Fluid Transient Effects

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Abstract: Liquid level control inside a subsea gas-liquid separator like VASPS, can be a difficult task. Nonlinearities of the dynamical system combined with disturbances on pipelines flow can result on randomness on liquid level behavior. The control approach chosen for the present study was a robust control generally applied to systems where parts of the dynamics are not well known. The Sliding Control despite of its reliability, induces discontinuities in the system that could be harmful to actuator, an ESP pump for VASPS case. Some adaptations were introduced in order to circumvent this problem. An imprecise system model using fluid transient theory was considered and numerically evaluated by method of characteristics. The present paper purposes a controller robust enough to keep the liquid level between specified limits, track a trajectory to be followed by level values along time and, additionally, able to avoid actuator overwork.

Keywords: Sliding Control, Subsea Separation, Fluid Transient, Method of Characteristics, VASPS.

1. INTRODUCTION

Gas –liquid separation applied by the oil industry over the last decades has been mostly based on gravity driven process. These kind of process are specially costly for offshore operations once it requires large and weighty vessel to be installed on the surface platform. As an alternative, it has been developed cyclone-concept separators wich are characterized by compactness, simplicity with no moving parts, low weight and reduced cost. Some of the well known processes are the Vertical Annular Separation and Pump System (VASPS), the Gas-Liquid Cylindrical Cyclone (GLCC) and the Cyclone Separator (CS). (Rosa, F.A., & Ribeiro, 2001).

VASPS, used as reference separator for this paper, is an UK patent application issued to British Petroleum in 1988 and designed for gas-liquid subsea separation. (Rosa, F.A., & Ribeiro, 2001). It consists of a vertical separator that receives multiphase fluid from the well in an intake chamber. The chamber is connected to liquid reservoir pool throughout a no moving helix. At the bottom of the assembly it is installed an Electrical Submersible Pump (ESP) used to raise the fluid to the platform. The separator has two separate pipelines: one for gas and other for liquid. The intake of the device is directly connected to the wellhead or to a manifold system, which receives the production from several wells. The separator is installed on the sea floor. (Melo, Mendes, & Serapião, 2007). An illustration of subsea production facility using VASPS is shown in Fig. 1.

The VASPS concept is often composed of three separation stages. The primary separator is an expansion chamber connected to an inlet nozzle that imparts momentum to the multiphase fluid and discharges it over a cylindrical wall along a tangential direction. The secondary separator is composed of a helix channel in which the mixture flows downward.

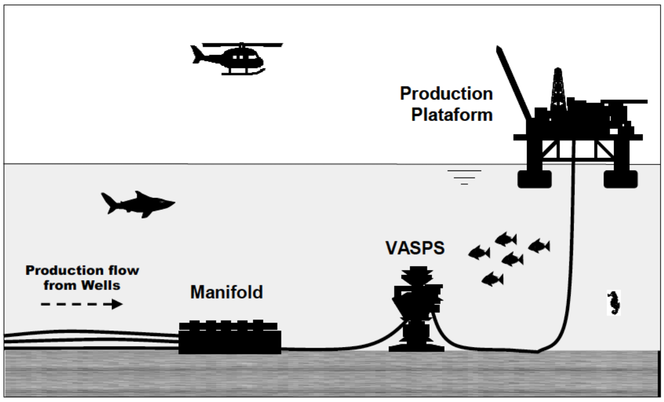

Fig. 1. Subsea production facilities. *(Melo, Mendes, & Serapião, Intelligent Supervision Control For the VASPS Separator, 2007)*

A tertiary separation stage is placed at the bottom of the separator and driven by gravity. At this stage the remaining bubbles dispersed in liquid film that reach the liquid reservoir are expected to be separated by gravitational action once the liquid stays enough time in the pool. (Rosa, F.A., & Ribeiro, 2001)

1.1 System Control

According to Pinheiro et. al. (2011), the control problem consists in maintain the liquid level inside an operational range by choosing the appropriated pump outflow. Out of the referred range two main troubles may occur. If the liquid level surpasses the maximum level specified, the useful area of conducting helix for the secondary separation stage will be reduced. This will lead to a decrease in separation efficiency. On the other hand, if the liquid level gets smaller then a specified minimum, a quantity of gas may pass through the pump causing serious damages. An important concern about gas-liquid separation control regards to its lifetime. As the system is installed in fake hole on the seabed any maintenance intervention would be costly. Any designed controller must take in account that the less the number of changes in command speed of the pump, the more its durability may be prolonged.

Difficulties in keeping specified range level arises from the fact that the system shows a nonlinear behaviour. The level inside the separator is a function of the inflow, which is generally present as slug regime, and a function of the gas pressure inside the separator which tends to change the liquid level in a hard to preview manner. Mello et. al. (2007), states that the disturbances caused by slug inflow allied to nonlinearities of the system may imply high randomness, what implies in a hard to predict control actions in order to maintain the desirable liquid level. Addressing the control issue, some different strategies can be found in specialized literature. Melo et al (2007), discussed an 'intelligent supervision control for VASPS separator'. Pinheiro et. al. (2009), adopted a stochastic intervention strategy in which the control was transformed in a sequence of iterated optimal stopping problems and then expresses it as a sequence of vibrational inequalities.

The present paper adopted a control approach using Sliding Control concept introduced by Slotine and Li (1991). The main benefit expected is to reach a reliable controller which can track a desirable curve set to get an optimal relation between actuator effort and level control. Sliding controllers can respond satisfactorily even when parts of the dynamical system are not well known. This can be very useful once it allows to simply disregard a huge part of the system dynamics simply knowing its values limits. Despite of the benefit of dealing with models uncertainties, the controller will have a discontinuous behaviour. Therefore, some adaptation had to be done in order to prevent abrupt changes in pump rotation speed and prolong its lifetime.

2. TRANSIENT FLUID THEORY FOR SYSTEM MODEL

Some simplified models have been used to describe the subsea gas liquid separator behaviour. Melo et al (2009), assumes a third order polynomial which is a pump rotational frequency function. The level time rate is given by the difference between separator inflow and outflow. Shiguemoto et al (2011) take an approach that considers transient fluid effects often present in real case. For its approach, two sets of differential equations presented by Wylie and Streeter (1978) are used, one to describe the liquid flow dynamics in liquid pipeline and another to describe the gas flow dynamics when it is being transported to the platform through its own pipeline. This modelling approach will be used for the present paper with slight differences. The model describes the liquid level inside separator as a function of piezometric head and outflow along liquid pipeline length and over the time. Additionally, the model incorporates changes in level made by gas pressure above the liquid column, where gas pressure is given in terms of mass rate flow and pressure along gas pipeline length and over the time.

For description of the system the equation of motion is derived for liquid flow through a cylindrical tube and is expressed in terms of the centreline of the pressure which is converted to *piezometric head* $H(x,t)$ and outflow $Q(x,t)$, where t and x are, respectively, time and position independent variables. Continuity Equation is written in terms of $H(x,t)$, $Q(x,t)$ and a value a that represents the speed of a sonic wave pulse of high pressure traveling upstream the pipeline at a sufficient pressure to apply just an impulse that brings the fluid to the rest. Motion equation and Continuity equations are shown in (1) and (2), respectively

$$g\frac{\partial H}{\partial x}+\frac{Q}{A^2}\frac{\partial Q}{\partial x}+\frac{1}{A}\frac{\partial Q}{\partial x}+\frac{fQ|Q|}{2DA^2}=0 \quad (1)$$

$$Q\frac{\partial H}{\partial x}+A\frac{\partial H}{\partial t}-Q\sin\theta+\frac{a^2}{g}\frac{\partial Q}{\partial x}=0 \quad (2)$$

In above equations A is cross sectional area of liquid pipe, f is Darcy-Weisbach friction factor, g is the gravitational acceleration and θ is the inclination of the pipe with respect to horizontal line, considering that the liquid has no transverse motion in its interior. The pulse wave speed is a quantity that depends on the bulk modulus of the fluid elasticity (K), the Young's elasticity modulus of the pipeline (E), pipeline thickness (e), the liquid density (ρ), a constant function of the Poisson Module of pipe material and diameter of the pipe (D). The wave speed value may be found using (3).

$$a=\sqrt{\frac{K/\rho}{1+(K/E)(D/e)C}} \quad (3)$$

The equation of motion had the forces acting over the fluid like pressure, friction and gravity forces equated to inertial forces. Although, inertial forces are less important than pressure and friction. Gas flow is subjected to transient effects of long and rapid duration, then equation of motion are adapted by the introduction of an inertial multiplier (α) in order to have an accurate numerical solution. For continuity equation, the formulation of the mass inflow in a short segment of the pipe is equalled to the time rate of increase of mass within this pipe segment. Both, motion and continuity uses state equation of natural gas (4). The equation of the state of the gas is

$$p = z\rho_G RT \quad (4)$$

Pressure (p) is given in terms of gas compressibility (z) which is considered constant during the time of solution, the gas mass density (ρ_G), the gas constant (R) and temperature (T). It is also assumed that during evaluation of the gas flow, the temperature is constant. The acoustic wave speed is written as in (5)

$$B=\sqrt{\frac{p}{\rho_G}}=\sqrt{zRT} \quad (5)$$

Continuity and motion equations for gas flow are presented in terms of the cross-sectional area of gas pipe (A), friction factor (f) and mass rate of flow (M) and gas pressure (p) along the pipe's distance (x) and time (t). Continuity and motion equations are shown in (6) and (7), respectively

$$\frac{B^2}{A}\frac{\partial M}{\partial x}+\frac{\partial p}{\partial t}=0 \quad (6)$$

$$\frac{\partial p}{\partial x}+\frac{\alpha^2}{A}\frac{\partial M}{\partial t}+\frac{pg}{B^2}\sin\theta_G+\frac{f_G B^2 M^2}{2DA^2 p}=0 \quad (7)$$

Besides assumptions already discussed, some others should considered for using transient gas flow theory. Expansion of the pipe wall may be neglected; each part of the pipe is considered to has constant slope; friction factor is function of wall roughness and Reynolds number; changes in Kinect energy along the gas pipe can be neglected; steady state values are used in transient calculations.

3. NUMERICAL SOLUTION USING THE METHOD OF CHARACTERISTICS

The main advantage of solving the model equations is to get liquid level as a function of pipeline flow transient disturbances. Therefore, model and the controller ability to deal with disturbances can be tested. This kind of disturbances appears, for example, when a valve is closed.The two set of equations, one for liquid flow and the other for gas flow, were numerically solved using the method of characteristics. Motion and continuity equations (1) and (2) are a pair of hyperbolic differential equations in terms of its dependent variables H and Q and its two independent variables, distance along the pipe (x) and time (t). Using the method of characteristics the partial equations are transformed in a set of four ordinary differential equations: the characteristic equations.

$$\left.\begin{aligned}\frac{g}{a}\frac{dH}{dt}+\frac{1}{A}\frac{dQ}{dt}-\frac{g}{Aa}Q\sin\theta+\frac{fQ|Q|}{2DA^2}=0\\ \frac{dx}{dt}=\frac{Q}{A}+a\end{aligned}\right\} C^+ \quad (8)$$

$$\left.\begin{aligned}-\frac{g}{a}\frac{dH}{dt}+\frac{1}{A}\frac{dQ}{dt}+\frac{g}{Aa}Q\sin\theta+\frac{fQ|Q|}{2DA^2}=0\\ \frac{dx}{dt}=\frac{Q}{A}-a\end{aligned}\right\} C^- \quad (9)$$

C+ and C- are the characteristic curves shown in Fig. 2. The evaluation of (8) and (9), gives the solution of the general partial differential equations (1) and (2). For solving them, however, it was necessary to adopt the method of specified time intervals. This method takes the known values at A, B and C (Fig. 2) and makes a linear interpolation to find H and Q values at R and S. Then a set of six equations must be evaluated in order to find values of H and Q at the point P, i.e., the values of the dependent variables Δt seconds after one had gotten the previous values. The computation continues until the maximum time desired is reached and each value of the dependent variable found at a given time t is used as known value for the next calculation step at time $t+\Delta t$. (Wylie & Streeter, 1978)

Specified time intervals method is used to numerically solve the set of equations (10) and (11), however, in this case it is not necessary to apply interpolations. The characteristics equations are evaluated in such way that its solution leads to steady state solution as special case of the unsteady or transient flow.

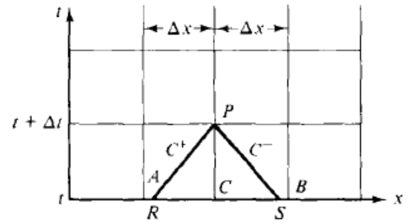

Fig. 2. Specified Time Intervals solves characteristic equations by using interpolations.

Method of characteristics applied to the set of differential equations for gas pipe flow defines the following characteristic lines along which its slope value compatibility equations are valid.

$$\left.\begin{aligned}\frac{\alpha^2}{A}\frac{dM}{dt}+\frac{\alpha}{B}\frac{dp}{dt}+\frac{pg}{B^2}\sin\theta+\frac{fB^2M^2}{2DA^2p}=0\\ \frac{dx}{dt}=\frac{B}{\alpha}\end{aligned}\right\} C^+ \quad (10)$$

$$\left.\begin{aligned}\frac{\alpha^2}{A}\frac{dM}{dt}-\frac{\alpha}{B}\frac{dp}{dt}+\frac{pg}{B^2}\sin\theta+\frac{fB^2M^2}{2DA^2p}=0\\ \frac{dx}{dt}=-\frac{B}{\alpha}\end{aligned}\right\} C^- \quad (11)$$

In other words, the solution must predict the steady state as a particular case when there is no change in conditions at a point along the pipe, with time. Steady state conditions and equations are discussed by Wylie and Streeter (1978).

For evaluation of inertial multiplier (α) it was used the procedure developed by Yow (1972), which was based on gas flow in a single horizontal pipe with sinusoidal variation of gas pipe input boundary conditions.

Both gas and liquid pipe transient flow are mixed initial-boundary value problems. Thereby, these values must be known for both cases. For the case of liquid pipe flow the pipe upstream contour will be given by the liquid column pressure value at the point in which the pipe is connected to the separation vessel (VASPS vessel) added by pressure increasing made by ESP pump work. The pressure increment (ΔH) realized by pump, in terms of piezometric head, is assumed to be the second order polynomial function of liquid outflow (Q_{pump}) given in (12)

$$\Delta H=\gamma^2 H_s+a_1\gamma Q_{pump}+a_2 Q_{pump}^2 \quad (12)$$

H_s, is the shutoff head and a_1 and a_2 are constants to describe the characteristic curve of the pump. γ is a dimensionless parameter which represents the pump rotation being a value between 0 and 1. The parameter can be found by between operation frequency and nominal frequency of the pump ($\gamma = f_{op}/f_{nom}$).

The final equation for liquid level (l) inside gas-liquid separator (VASPS) is achieved by a first order differential equation where the level time rate is proportional to the difference between the inflow (q_{in}) and the outflow (q_{out}) of the separator vessel.

$$\frac{dl}{dt} = \frac{1}{A_{vessel}}(q_{in} - q_{out}) \qquad (13)$$

A_{vessel} is the cross sectional area of the VASPS.

For subsea gas-liquid separators inflow is expected to be a signal that represents properties of the flow generated by the well. Among other patterns, slug and severe slug are regimes expected to be observed in practice. Other entering signals can be useful to study the controller performance as signals that represents constant inflow and sinusoidal like inflow pattern.

The method of the characteristics lead to an outflow equation derived by the equation of the pressure increment realized by pump (12)

$$Q_{pump} = \frac{B - a_1\gamma}{2a_2}\left(1 - \sqrt{1 - \frac{4a_2(\gamma^2 H_s + p_L/\rho g - C_M)}{(B - a_1\gamma)^2}}\right) \quad (14)$$

The pressure at height (l_c) at which the pump is placed and the liquid outflows, is assumed to be a sum of the pressure due to liquid column added by gas the pressure inside the VASPS vessel.

$$p_L = p_G + \rho g(l - l_c) \qquad (15)$$

The space inside the separator occupied by the gas phase is theoretically assumed to be a segment of the gas pipeline with a variable diameter which corresponds to the height of the vessel subtracted by the liquid level (l). Gas pressure (p_G) inside the vessel will be taken directly from the solution of (10) and (11) at the correspondent point in gas pipeline.

C_M in (14) is a function of pressure and flow at a point Δx distant of the point where the liquid pipeline is connected to the vessel in a time immediately before (t-Δt) the time computed for the numerical solution.

$$C_M = f(H(\Delta x, t - \Delta t), Q(\Delta x, t - \Delta t)) \qquad (16)$$

H and Q are, at the end, a difficult to determine function of liquid level. One can notes that H or Q value at a point Δx, for a determined time (t-Δt), are given by methods of characteristics as functions of H and Q at points (Δx-Δx=0) and (Δx+Δx = 2 Δx) at a time (t-2Δt). As pressure and flow are function of liquid level at the connection point of pipe and vessel, C_M can be seen as a function of liquid level.

The applied nonlinear control theory classifies this uncertainties about system as unstructured uncertainties, which are ones that comes from unmodeled dynamics.

3. SLIDING CONTROL FILTERED FOR VASPS REQUIREMENTS

Slotine and Li (1991), present the Sliding Control as being a control approach to deal with models uncertainties, classifying it as a robust control. Robust control structure is composed by a nominal part similar feedback linearization and another part designed to deal with system uncertainties. Sliding control is then a robust control based on the remark that it is easier to control a first order system then try to control a not well known nonlinear system. Note that if the system were completely known, a feedback linearization approach would be enough.

For control purposes, the gas pressure (p_G) inside VASPS vessel in (15) and the function C_M in (14) were assumed to be not exactly known, but with the extent of its imprecision bounded by known continuous time functions: $p_G \le \widehat{p_G}(t)$ and $C_M \le \widehat{C_M}(t)$.

Once the uncertainties limits were established the aim is to get the system state $\boldsymbol{l} = [\ddot{l}\ \dot{l}\ l]^T$ (liquid level (l) and level time rate ($\dot{l}$)) to track the desirable time varying state $\boldsymbol{l_d} = [\ddot{l_d}\ \dot{l_d}\ l_d]^T$ in the presence of model imprecision in p_G and C_M.

Neglecting high order effects that can act over the system by the unknown function p_G and C_M, the system can be treated as a first order differential equation and sliding surface reduced to track error

$$s(\boldsymbol{x}, t) = x = l - l_d \quad (17)$$

Slotine and Li (1991) states that the nonlinear uncertain nth-order system converted to an nth-order tracking problem using the sliding surface (17), can be replaced by a first-order stabilization problem. This new first-order problem of keeping the s at zero can be achieved by choosing a convergence law that satisfies the *sliding condition* (18)

$$\frac{1}{2}\frac{d}{dt}s^2 \le -\eta|s| \qquad (18)$$

The proposed controller in this paper to satisfy the sliding condition and control VASPS system is shown in (19)

$$u = \sqrt{\left(\widehat{C_M} - \frac{\widehat{p_G}}{\rho g} + \frac{B^2}{4a_2} + \varphi^2\right)\frac{1}{H_s}} \qquad (19)$$

With $\varphi = 1 - \frac{2a_2}{B}\,q_{in} + \frac{2a_2}{B}\,\dot{l}_d A_{vessel} + sign(s)$

The function *sign(s)* is defined by

$$\begin{cases} sign(s) = 1, & s \ge 0 \\ sign(s) = -1, & s < 0 \end{cases} \qquad (20)$$

3.1 Adaptation of controller to VASPS requisites

The controller response is very satisfactory when dealing with the first concern about VASPS control: maintain the liquid level inside a specified limits range. However, this result is based on the idea that the value of γ is not limited. In addition, the control law purposed in (19) just works if its inability to assume negative values is respected. The advantage of this control approach is the possibility of forcing the system state $\boldsymbol{l}$ to follows the desirable state $\boldsymbol{l_d}$. By choosing $\boldsymbol{l_d}$ as a smooth trajectory one may find an optimal trade-off between liquid level range and the minimum effort made by actuator, the ESP pump. However, sliding control is a discontinuous control. In order to account for the presence of modelling imprecision and disturbances, the control law has to assumes a discontinuous behaviour across *s(t)*, the discontinuity at the present case is caused by jumps produced by (20) when *s* switches its sign. In practice, these switches are not instantaneous and value of *s* is not known with infinite precision. In the VASPS case, the ESP pump will not change rotation discontinuously and a control law which forces the pump to do so, can significantly decrease its lifetime.

It is clear that the general convergence law (18) depends upon of system state, which includes high order derivatives. However, the controller (19) only depends on zeroth order derivatives of the level. For practical implementations purposes, this approach can reduce problems with measurements noise since there is no need to high order measurements.

In order to get an applicable controller output was filtered by a second order filter as in (21).

$$m\ddot{\gamma} + b\dot{\gamma} + k\gamma = u' \quad (21)$$

For above equations *m*, *b* and *k* are strictly positive nonzero constants. In addition, a control logic was imposed to represent the actuator saturation and introduce a dead zone for liquid level to avoid actuator overworking. The control logic is presented below

$$\begin{cases} u' = 1, & if \quad u > 1 \\ u' = u, & if \quad l > \ l_d + \delta \\ u' = f(l)u, & if \quad l_d - \delta \leq l \leq \ l_d + \delta \\ u' = 0, & if \quad l < \ l_d - \delta \end{cases} \quad (22)$$

Where *u* is given by (19) and δ is the tolerated distance of level (l) from the desirable level (l_d) at a given time.

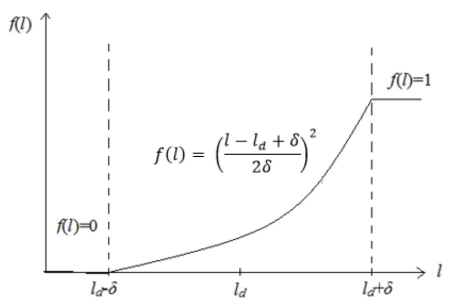

Fig. 3. $f(l)$ is quadratic function inside tolerance limit range.

As γ which represents the pump rotation, is a value between 0 and 1, *u'* must be limited to a maximum value as in (22). When the distance between the liquid level inside the separator and desirable level at a given time is greater than a tolerable value, the controller is expected to act fast, then *u'* assumes the value calculated in (19). Values of level inside the range given by the second line of (22) are treated by a second order function which is zero when liquid level reaches the low tolerance limit ($l = l_d - \delta$), and equals to unit when the level reaches the up tolerance limit ($l = l_d + \delta$). The second order function $f(l)$ is shown by Fig. 3.

The filter solution adopted and even a different approach using a smooth switching function can slow the response down, but this is not expected to be a significant problem if the level range is respected. In the other hand, the filter solution can preserve the actuator preventing abrupt changes.

5. RESULTS

Some representative cases were simulated using MATLAB software. The subsea separator was modelled as a 50m height cylinder with 1 meter of diameter. The tolerance range was δ = 0.1m and the ESP was assumed as having a maximum head H_s=2000m and a maximum flow rate of 0.18m^3/s. 10 pipelines with 0.25m inner diameters were set for the liquid and 5 pipelines with 0.5m of diameter for the gas. A square wave of amplitude q_{in_max}=0.01m^3/s was used to represent the slug inflow. To illustrate the improvement that may done by adjustment of the introduced second-order filter, the purposed scenario was simulated considering the filter as having inertial and damping coefficient as shown in (22)

$$4\ddot{\gamma} + 8\dot{\gamma} + \gamma = u' \quad (22)$$

Intending to observe the controller action, the actuator was forced to work before it is expected to, when considering real inflow signal amplitude. For that, the angular frequency of square wave was set at 0.1 rad/s. The controller was set to track a quarter of a sinusoidal curve starting at $l_d=2.5$ in the beginning of the simulation and ending at $l_d=2$, 350 seconds after.

Even under tough operational specifications like small tolerance diversion from pursued curve, the liquid level inside the separator (Fig. 5 solid line) followed the desirable curve (Fig. 5 dotted line) with a good precision and managed to maintain a satisfactory actuator effort.

Fig. 6.1 shows the actuator effort represented by γ parameter. After the increase in pump rotation needed to bring the level from initial 2.5m to resting level at 2.0m, the rotation decreases and pump starts working with peaks of about 4% of its maximum capacity. In enlarged detail (Fig. 6.2) one notes that pump takes approximately 60 seconds to reach the peak-to-peak maximum rotation imposed by the controller in order to maintain the level inside the tolerated limits range. The second-order filter dynamic forces the actuator to follows a smooth curve what helps to increase the pump lifetime since abrupt changes are no more allowed.

Wide number of adjustment possibilities can be applied to the controller proposed by this paper. Once applied the filter one can adjust the coefficients in (21) to get a satisfactory relation between level controlling and actuator saving. An increase of the inertial equivalent coefficient m in (21), for instance, will force the pump to respond slower to a change required by control driver described in (19). Different time responses and converging behaviours can be achieved using different values for coefficients m, b and k in (21).

In order to observes the controller ability to deal with strong disturbances, a valve half closing was admitted at 4000s simulation time. It was observed that even under perturbation effect the convergence was maintained and level trajectory stills tracking the desired curve.

As shown in Fig. 6.3, once the liquid level was stabilized around the value established by desired reference curve, peak-to-peak time distance of curve described by γ did not change during simulation time period, remaining in approximately 60 seconds. The amplitude of the curve the oscillatory curve is approximately 0.025 and the curve presented a very smooth behaviour what means that the actuator, or ESP pump, did not suffer fast changes in its frequency rotation. Both the smaller amplitude and smooth curve implies less changes in rotation velocity, therefore helps to increase pump lifetime.

The change in dynamic imposed to the pump was made intending to get a slower response. As result, the time the controller took to stabilize liquid level around final value of desired reference curve was delayed. Its observed in Fig 6.1 that the second-order filtered controller took more than 1500 seconds to stabilize the liquid level according to desired curve.

After 4000 seconds Fig. 6.3 shows a fast increase pump effort γ. At this time a valve placed at the end of liquid pipeline was half closed. This disturbance causes the controller to work more forcing pump to rotate faster in order to keep level requires. The pump rotation increase is observed in Fig. 6.2 as an increase on γ curve at 4000 seconds. Despite of the strong disturbance liquid level still attending requisite demands and no divergences were seen.

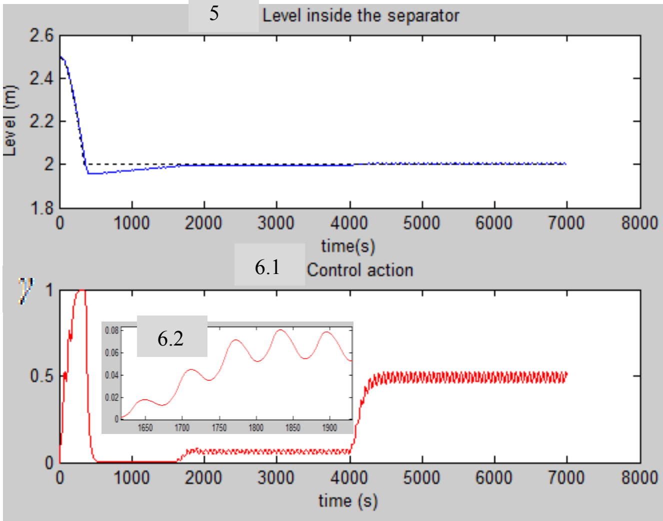

Fig. 5- level inside separator (desired curve dotted line, level curve in solid line). 6.1 - γ behaviour. 6.2 – enlarged detail of γ behaviour.

6. CONCLUSIONS

Sliding control showed to be a useful tool for dealing with subsea separator liquid level control problem. Model uncertainties and nonlinearities are compensated by controller which promptly tracked a desirable position curve. The main advantage of the curve tracking is the later possibility of use it to set an optimal relationship between level positioning and actuator saving. Discontinuities imposed by the controller were, as expected, redressed by the proposed filter which managed to maintain level close to desired curve values, therefore, level value limits were respected. Later studies will submit proposed controller to more realistic mild requisites as wider range tolerance limits for liquid level, and compare its performance with other controllers already developed and discussed in literature. Some discussions are important to later improvements, among them one can highlight an stability analysis to demonstrate the stable region of the closed-loop system.

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