Simulation of subsea control systems

1 Introduction

For almost 20 years the oil industry has been using computers for the design of hydraulic lines in umbilicals. The need for accurate calculations is heightened by the fact that the umbilical is one of the most expensive individual components in a subsea installation. If it is wrongly dimensioned, it will result in major time and cost overruns.

In this article we set out how a model for simulating this kind of system can easily be set up and designed using SimulationX® software. The model is based on the available information from the various suppliers of this kind of system.

We have chosen to look at a system for the completion and work over of subsea wells. The principle is identical for traditional subsea production systems.

2 System specification

A typical completion and/or work over system for subsea wells consists of four main components.

1. Hydraulic power unit (HPU)
2. Umbilical.
3. Subsea control module (SCM).
4. Valve actuator.

Figure 1 shows a typical system with two valve actuators and return to sea.

![Figure 1. System diagram](image)

Each of these main components can be modelled in SimulationX® with the aim of reusing them in subsequent systems. This can be done by saving the models as new elements and including them in the user library. All these user elements can later be retrieved and used together with the standard library in other models involving similar components.

3 Hydraulic power unit (HPU)

The pumping unit for these systems is normally located on the deck of the vessel from which the operation is being run. There are different types of pumps, but the most common type uses accumulators that are charged by fixed pumps. These are controlled by a Programmable Logical Controller (PLC), and start and stop at various pre-programmed pressures.

Figure 2 shows a simplified schematic diagram of a pumping unit as described above.

![Figure 2. Simplified schematic diagram of a pumping unit (HPU)](image)

The pumping system is modelled as shown in Figure 3. Please note that it is an advantage to limit the size of the model by leaving out components which are not active in the sequences that we will be looking at. This is because all of the elements included in a model are included in the calculations, taking up part of our computer’s capacity. This is also the case for passive components such as safety valves for pumps, etc.

![Figure 3. Pumping system modelled in SimulationX®](image)

To make models easy to reuse, it is important to keep them tidy and clearly laid out. The documentation must be easily accessible so that the next user can quickly get to know the structure of the model. Our experience is that many people are careless about this, making it impossible to share models with engineers internally at a company.

To allow the pumping model to be reused in subsequent analyses, it should be added to the user library under “user elements”. Simple documentation should be drawn up to give users a brief introduction to the model. This user documentation is linked to the element and can easily be retrieved from the element’s parameters window.
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4 Umbilical

All hydraulic communications go through separate hoses or pipes that are bundled together into an umbilical. In temporary systems, which is what we are looking at here, hoses are most common. These hoses have properties that must be taken into consideration in any simulation. The ability of hoses to accumulate liquid can be a disadvantage in systems that require the rapid bleeding of lines. But this property can also be turned into an advantage in systems where large actuators are to be operated. Using hoses with high volumetric expansion can in some cases replace accumulators on the seabed.

The design of the umbilical is important to the performance and operation of the whole system. It is therefore important that the model of the hose is accurate, and that it includes the delays that are experienced in practice.

It is an advantage to use a “distributed” line model in which the line is split into several separate elements as shown in Figure 5.

A distributed line model is in simple terms a series of line elements in which each line element calculates the restriction, inertia/acceleration of the fluid as well as the flow. Between each line element, the pressures are calculated as a function of the flow from the previous linear element, flow to the next linear element and the line’s volumetric coefficient of expansion (Ve).

In this type of line model, time delays in long lines can be calculated with great accuracy. This is important for systems in which the pressurisation and bleeding of lines are used as methods of Emergency Shut Down (ESD). These functions often have strict time requirements that can be simulated and later verified in tests.
5 Subsea control module

Today’s systems are usually designed with a subsea control module from which the valve is operated. There are many types of subsea control modules, but the majority include an incoming supply line and return lines that operate various types of actuators. The number of lines and the instrumentation varies from supplier to supplier, and depends on the type of application that is to be operated by the subsea control module.

Figure 8 shows a simplified schematic diagram of a subsea control module that can form the basis for a model.

Figure 8. Simplified schematic diagram of a subsea control module.

Subsea control systems often use water-based oils, and therefore allow return oil to be released into the sea in limited amounts. The simplified schematic diagram in Figure 8 shows this type of return system. As previously mentioned, it is important to limit the number of elements in a model to the elements that are active in the sequences that we will be looking at. In Figure 9 there is a subsea control module modelled in SimulationX® with the necessary number of valves, which is two.

Figure 9. Subsea control module modelled in SimulationX®.

The parameters for the elements in the control module can be based on catalogue data for the control valves and connectors, as well as on geometric values for the borings in the manifold. There are often test results for the drop in pressure through the control module. We recommend using these test results and modelling the control valve with this drop in pressure.

As we did with the pumping unit, we save this detailed model of the control module for later use. The model is therefore saved as a new user defined element with an easily recognisable icon (Figure 10).

Figure 10. Control module represented by an icon alongside a parameters window.

6 Valve actuator

The valve actuator for a subsea gate valve is often a linear actuator. Including the valve seals (gate and poppet valves) as shown in Figure 11, the model will be somewhat more complicated on account of variable friction.

Figure 11. Drawing of a typical gate valve in closed and open positions.

When this type of valve is to be modelled, it is often worth looking at the valve as an isolated system and breaking down the properties of the valve into smaller elements. This makes it easy to include all of the special properties of each element in a model. In SimulationX® a typical model of a gate valve with an actuator will look like Figure 12.
We can see that the valve’s individual elements are represented by basic elements such as areas, mass, springs, etc. Each individual element represents a function of the valve, and it is now easy to set up these functions with their respective dependent variables.

As previously mentioned, friction is variable in this type of valve as shown in Figure 13.

We can see that the valve friction starts at 10910 N, and when x-Piston passes 12.65 mm (at t=3.2 s) the friction falls to 6730 N.

Finally, the detailed valve model is saved as a user defined element in the same way as for the pumping unit and control module.

Figure 12. Gate valve modelled in SimulationX®.

Figure 13. Plot of friction and piston position.

Figure 14. The gate valve represented by an icon alongside a parameters window.

7 System model

So far we have finished defining all of the main components for a model of the complete system. What now remains are the simple standard elements such as restrictions in connectors and internal pipes and hoses, etc. which are easy to set up as you piece together the complete system model.

Figure 15. Complete system model

Figure 15 shows the complete system model as it now appears in SimulationX®. We can recognise it from the system diagram in Figure 1. This kind of graphical presentation of the models makes them much easier to reuse and share.

7.1 Results from the system model

When the system model has been completed and all of the parameters have been added, the simulation itself can start. It is important to clearly understand clearly what you want to demonstrate through these simulations. Often it is sufficient to demonstrate that the requirements of standards and specifications are met. We have chosen to show three sequences in this article.

- Pressurisation of a line in the umbilical
- Operation of a gate valve
- Emergency Shut Down (ESD)

Pressurisation of a line in the umbilical.
Here our initial status is that the HPU is ready with full accumulators and the umbilical supply line is vented to return. After 1 second the HPU valve opens and pressurises the line. The umbilical line is 600 metres long, and has an internal diameter of 3/8". Transaqua HT has been chosen as the hydraulic fluid.
The subsea equipment is at a depth of 500 metres, and with the chosen fluid, the fluid column will be approx. 54 bar of pressure in the line at the bottom. This can be clearly seen at the start of the blue line in Figure 16. Furthermore, we can see that it takes approx. 0.3 seconds from when we start pressurising the line until we see a reaction at the other end. The whole filling sequence takes slightly less than three seconds.

**Operation of a gate valve**

During the operation of a gate valve, it is important to check whether the operation affects other valves in the system. This is done by operating a valve at the same time as monitoring the pressure drop in the actuator’s initial volume at another valve. If the drop in pressure is so great that other valves might start closing, the system is under-dimensionalized. The options that we then have are usually to increase the dimensions of the lines in the umbilical or to install a subsea accumulator. Both options will affect the time it takes to pressurise the umbilical, and to bleed it when shutting down.

The model is now set up with two gate valves and we operate one valve whilst the other is set in the open position.

Figure 17 shows the pressure and position during the operation of a gate valve. The opening time is approx. 3.5 seconds and the pressure differential over the actuator piston is approx. 94 bar when open and 82 bar when closed.

Figure 18 shows the pressure and position for the open gate valve. We can see a clear drop in pressure when the other gate valve is opened. The pressure drop across the actuator piston is however still a long way off 82 bar, which is the measured pressure drop as the valve starts to close. We can safely say that our system is appropriately designed for these two valves. At this point, maybe we could attempt to reduce the dimensions of the line to see if we can achieve satisfactory results whilst making the umbilical cheaper?

We must also investigate whether the drop in pressure between the supply line and the return line to the subsea control module is higher than the control valves’ re-set pressure, which is set at 40 bar in this model.

Figure 19 shows that the drop in pressure between the two lines is way above the valves’ re-set pressure.
Emergency Shut Down (ESD)

All systems of this type are built so they automatically shut down if an accident occurs. These shut downs should not be dependent on the power supply. The normal solution is to design the system in such a way that the gate valves close if the pressure is bled off up at the pumping unit.

We can see from Figure 21 that the gate valve is completely closed after approx. 8 seconds. If the system had been set up with bigger valves and subsea accumulators, more liquid would need to be bled off via the umbilical. Naturally, the whole shut down sequence would then take longer time.

8 Summary

By using a simulation tool we can test a system virtually before putting it into production. Various alternative solutions can be tested, and the results will form the basis for choosing the components and dimensions to be used.

When using a tool with existing libraries and a graphical interface, a good understanding of the system and of the individual components is much more important than detailed mathematical knowledge. An understanding of the applications is particularly important when interpreting the results of the simulations.

Simulation software will also allow you to test the systems in ways that are not practicable in real life. This may involve testing with pressures that are far higher than the system pressure, or with accumulators with severe gas leakage.

If a company wishes to start using modelling and simulation, it is important to note that this will not replace part or all of the development process. It is, however, a supplement that will help engineers to design a better product to a lower cost.

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