Application of SIMULINK to Emulate Subsea Production System (SPS) Control Functions

by

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Dissertation in partial fulfillment of
the requirements for the
Bachelor of Engineering (Hons)
(Mechanical Engineering)

JUNE 2009

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
Mechanical Engineering Programme
Universiti Teknologi PETRONAS
in partial fulfilment of the requirement for the
BACHELOR OF ENGINEERING (Hons)
(MECHANICAL ENGINEERING)

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JUNE 2009

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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KHAIRUL FARIZ BIN KHALIL

ABSTRACT

Subsea control systems in subsea production system (SPS) play a vital role in the safe and productive operation of any oil or gas field. These systems operate in extreme environments, thus making the installation and commissioning the system risky and costly. For a new developer, a better understanding on how the system works is needed to ensure that the system will meet all design specifications and reduce the risk and costs associated with installation and commissioning. Hence, leading oil and gas companies are turning to simulation software where the whole subsea control systems from the Hydraulic Power Unit to the Subsea Control Module can be modeled. This project aims to develop a SIMULINK model for a specific SPS and to assist in ensuring that the system will function accordingly. The scope of the project is to concentrate on the movement of the gate valve in subsea control system where the flow of an oil and gas is controlled. The methodology of the project involves collection of technical details and data regarding subsea control modules, identify elements of the control system, arrangement block diagram notation of the SIMULINK software, the acquisition of the SPS design parameters, and the development of SPS control system equation. Simulation result shows that the gate valve is fully open at 10cm within 0.075s. This will be useful to conduct a sensitivity analysis in the matter of SPS changing key design parameters. Moreover, this project will give lots of advantages to a new developer to understand the system well before developing the actual SPS control system.

ACKNOWLEDGEMENTS

I would like to express the deepest appreciation to my supervisor, AP Dr Fakhruldin bin Mohd Hashim, who has the attitude and the substance of a genius: he continually and convincingly conveyed a spirit of adventure in regard to research and scholarship, and an excitement in regard to teaching. Without his guidance and persistent help this dissertation would not have been possible.

I am also indebted to the Final Year Research Project Coordinator, Prof Dr. Vijay R Raghavan and Dr. Puteri Sri Melor bt. Megat Yusoff for provide me with all the initial information required to begin the project.

Special thanks to my beloved family who have been supporting, understand, and encourage me in completing this final year project. Last but not least, to all individuals that has helped me in any way, but whose name is not mentioned here, I thank you all.

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ABBREVIATIONS AND NOMENCLATURES

Abbreviations

ESD	Emergency Shut Down
FYP	Final Year Project
HPU	Hydraulic Power Unit
PLC	Programmable Logic Controller
SCM	Subsea Control Module
SPS	Subsea Production Systems
Ve	Volumetric Coefficient of Expansion

Letter Symbols

c	Spring constant
c_d	Discharge coefficient
d	Damping coefficient
g	Gravitational acceleration
k	Discrete number
m	Mass
p	Pressure
t	Continuous time
v	Speed, specific volume
x	Space coordinate
z	Space coordinate
A	Area
E	Module of Elasticity
F	Force/fluid force
F_c	Spring force
F_d	Damping force
F_p	External force
Q	Volume flow rate
V	Volume

X	Space coordinate
Z	Space coordinate

ρ	Mass density
ζ	Resistance coefficient
Re	Reynold Number
β	Bulk modulus
κ	Fluid compressibility

CHAPTER 1
INTRODUCTION

1.1 BACKGROUND OF STUDY

Over the last decade, there has been a development in the application of subsea systems for the production of oil and gas from subsea wellheads. The elements of subsea production system (SPS) consist of a wellheads and trees; pipelines and end connections; controls, control lines, and control fluids; templates and manifolds; and production risers [API1996]. In many instances, a number of wellheads have to be controlled from a single location. A subsea control system is a part of SPS, and proper performance of the control system is a critical factor in ensuring the control system is reliable and safe operation.

1.2 PROBLEM STATEMENT

Nowadays, oil and gas industry requires continuous development of new technologies in order to produce oil effectively. By development of a new and improve system in SPS, a modification of its key design parameters shall be done. Hence, a sensitivity analysis needs to be conducted by simulating the SPS. A proper SPS simulation system may need to be developed and tested for use to observe the response of its changing key design parameters. By using a simulation tool, the system can be tested 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. Simulation will also allow us to test the systems in ways that are not practicable in real life. Besides, there will be severe errors of the subsea system if it is produced without any simulation. For example, a movement of the gate valve in SPS needs to be observed in SIMULINK in order to meet the system specification before it can be operated. Furthermore, the simulation will give benefit to a new developer by provide a better understanding on how the control system in SPS operates.

1.3 OBJECTIVE AND SCOPE OF STUDY

The objectives of the project are:

a) To develop a SIMULINK model for a specific SPS.
b) To simulate the control module functions that govern the associated SPS operations.

The scope of the study covers a typical direct hydraulic control system of SPS principal operation where it focuses on a movement of the gate valve in order to control an oil or gas flow in SPS. Moreover, commercial SPS from certain manufacturers will be identified and its key design parameters will be used to build the simulation model.

CHAPTER 2
LITERATURE REVIEW

2.1 SUBSEA PRODUCTION SYSTEM

Subsea production systems are wells located on the sea floor, as opposed to at the surface. Subsea systems are typically in use at depths of 2,000 meters or more, and do not have the ability to drill, only to extract and transport. There are several equipments involved directly in SPS [Daley1996]:

a) Wellhead, tubing hanger, X-mas tree with choke, completion workover riser, workover control system.
b) Production Control System: typically include subsea control module electronics and hydraulics, subsea electrical/hydraulic and chemical injection distribution system, tree instrumentation, etc
c) Umbilical: electrical, hydraulic and chemical lines including terminations.
d) Intervention system: typically include tools for pull in and connection of sealines/umbilicals, tools for running of choke, control pod, pig launcher etc., surface control container, umbilical winch, lift wire winch, heave compensation equipment etc.
e) Subsea structures and piping systems: template and satellite structures, manifold and riser base structures, protection structures, piping modules.
f) Subsea flowlines: any risers, hard pipes, flexible lines, rigid risers, dynamic risers.
g) Subsea processing: metering, boosting, separation, water injection etc

2.2 TYPES OF PRODUCTION CONTROL SYSTEM

A production control system provides the means to control operation of a subsea production facility. There are several types of control systems:

a) Direct Hydraulic Control System
b) Piloted Hydraulic Control System
c) Electro-Hydraulic Piloted Control System
d) Electro-Hydraulic Multiplexed Control System
e) Subsea Powered Autonomous Remote Control System

2.2.1 Direct Hydraulic Control System

Direct hydraulic control system is the simplest type of control system in which Hydraulic Power Unit (HPU) and well control panels for each individual well to be controlled are located topside. Well control panels use solenoid-operated control valves. Hydraulic signals are transmitted via umbilicals to actuators of production control valves mounted on the subsea tree. Each actuator of a tree-mounted production valve has a separate supply line. When used, a subsea control module (SCM) is the interface between the control lines, which supply hydraulic and/or electric power and signals from a surface facility, and the subsea facility to be controlled. It is generally mounted on a base from which it can be removed for maintenance or replacement. The SCM contains pilot valves powered by hydraulic fluid or electric power (or both) which is supplied from a surface facility. If specified, the module can also contain electric or electronic components that are used for control, communications or data gathering. The advantages of this type of control are relative simplicity, high reliability, ease of service and minimization of a number of subsea components. However, the umbilical is complex because it must contain all individual hydraulic lines for all controlled tree components. [API1996]

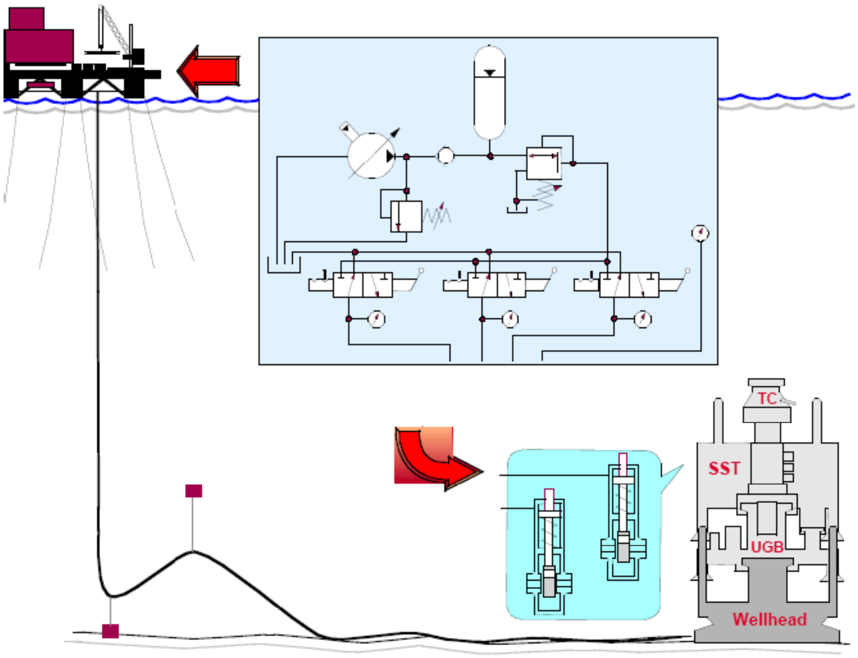

Figure 2-1: Direct Hydraulic Control System [Stecki1998].

2.2.2 Hydraulic Control System Model Specification

A typical completion and/or work over the system consist of four main components. There are hydraulic power unit (HPU), umbilical, subsea control module (SCM), and valve actuator. Figure 2-2 shows a typical system with two valve actuators and return to sea.

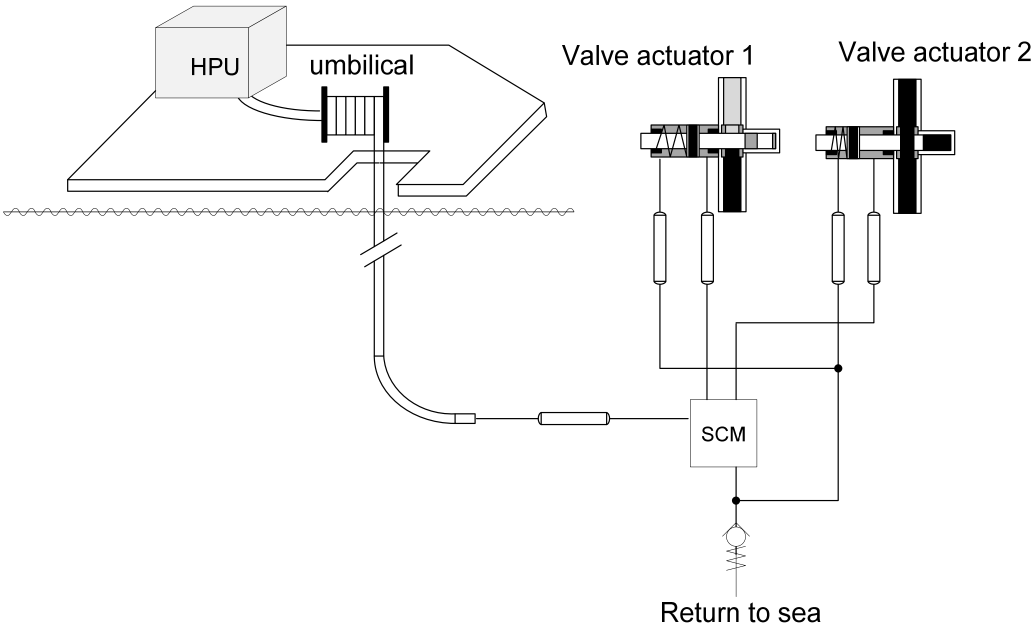

Figure 2-2: System Diagram of Hydraulic Control [Agito2008].

2.2.3 Hydraulic Power Unit (HPU)

Normally, the pumping unit for these systems is located on the deck of the vessel from which the operating is being run. In hydraulic power unit, it contains pump which is converts the available (mechanical) power from the prime mover (electric or diesel motor) to hydraulics power at the actuator. Pump is a part of an auxiliary unit that can be considered simply as a source of hydraulic power. 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 2-3 shows a simplified schematic diagram of a pumping unit as described above.

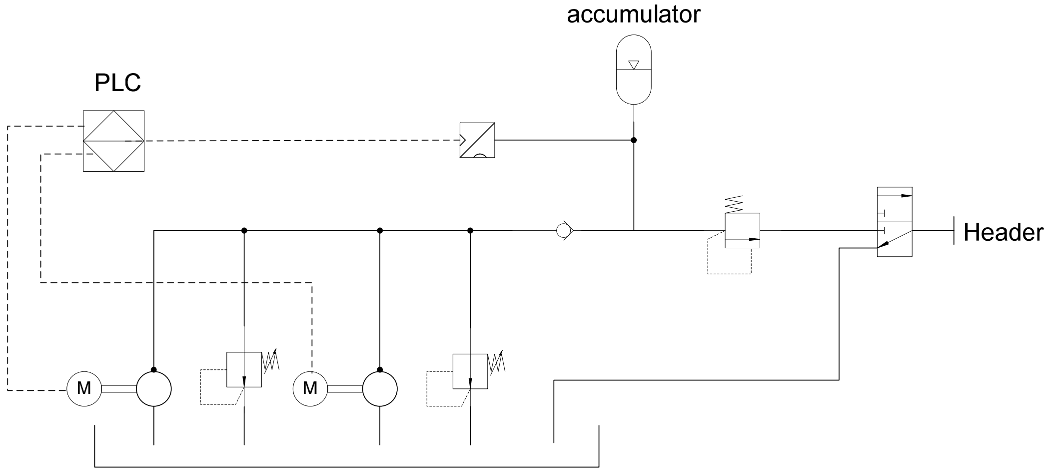

Figure 2-3: Schematic Diagram of a Pumping Unit (HPU). [Agito2008]

2.2.4 Umbilical

The supply and return lines are normally installed in a so-called umbilical, usually together with other hydraulic, electrical, and/or optical lines, and/or lines for the supply of other fluids. The umbilical extends from the subsea process control valve near the well to a platform. The umbilical may be very long, in some cases up to 20 km or more. In the umbilical it is desirable to employ hydraulics lines with limited cross section. A typical diameter for the umbilical may be approximately 5cm, and the lines which are installed in the umbilical may have a diameter of approximately 12mm. The flow resistance in the hydraulic lines then becomes substantial, with the result that the response time for the valve actuator in the system may be unsatisfactorily long. In temporary system, 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.

2.2.5 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 includes an incoming supply line and return lines that operate various types of actuators. In subsea control module, it consists of directional valve which is control spool position or orifice area. A valve is variable area orifice where the orifice area may be controlled by conditions in a circuit. Alternatively the orifice area may be controlled by an operator as in a directional control valve. This categorization is a quite simplistic because not all directional control valves are directly linked to an operator. 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 2-4 shows a simplified schematic diagram of a subsea control module that can form the basis of the subsea control module operation.

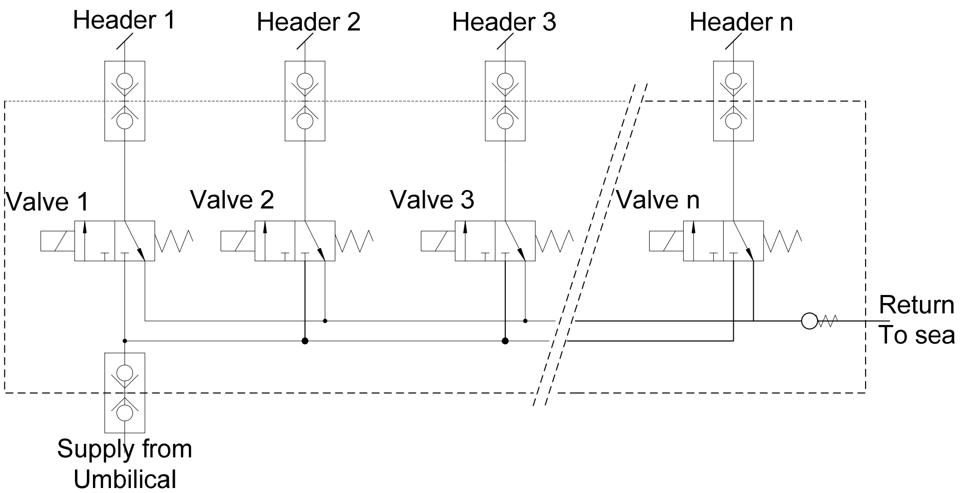

Figure 2-4: Schematic Diagram of a Subsea Control Module. [Agito2008]

2.2.6 Valve Actuator

In order to control an oil or gas flow from a well, the well is provided with a wellhead Xmas tree comprising process control valves, where each process control valve is provided with an actuator for operation or the valve. The actuator may be operated electrically or hydraulically, but hydraulically operated actuators are normally employed for wellhead Xmas trees in oil and gas production. In the case of so-called open systems, hydraulic cylinder may be employed to which there extends only one single line, which is connected to one of the chambers. The second chamber communicates with the space surrounding the actuator, and in this chamber there may be mounted a return spring which attempts to move the piston part towards the first chamber. In order to move the actuator's movable part towards the second chamber, the line is supplied with a pressurized fluid whose pressure is so great that a force is generated which is greater than the force exerted by the spring. In order to move the movable part in the other direction, the pressure on the fluid in the line is reduced, whereby the return spring causes the movement of the movable part in the other direction while at the same time the fluid is forced back in the line. 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 2-5, the model will be somewhat more complicated taking into account of variable friction.

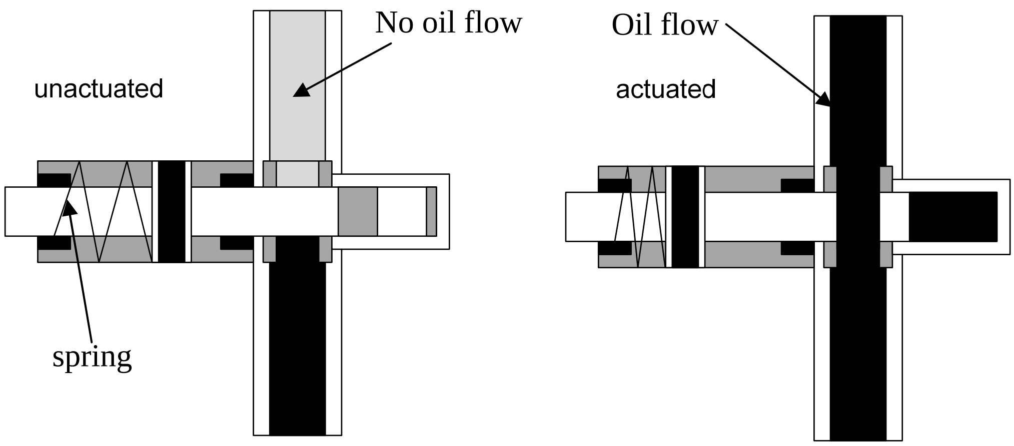

Figure 2-5: Drawing of a Typical Gate Valve in Closed and Open Positions. [Agito2008]

2.3 SIMULINK

SIMULINK is an extension of the MATLAB software that allows engineers to rapidly and accurately build computer models of dynamical systems using block diagram notation. Using SIMULINK, it is easy to model complex nonlinear systems. A SIMULINK model can include both continuous and discrete-time components. Additionally, a SIMULINK model can produce graphical animations that show the progress of a simulation visually, significantly enhancing understanding of the system's behavior. [Dabney&Harman1998]

2.3.1 SimHydraulics

SimHydraulics is a modeling environment for the engineering design and simulation of hydraulic power and control systems within SIMULINK and MATLAB. It is based on the Physical Network approach of Simscape and contains, a comprehensive library of hydraulic blocks that extends the Simscape libraries, of basic hydraulic, electrical, and one-dimensional translational and rotational mechanical elements and utility blocks. [Mathworks2007]

2.3.2 Assumptions and Limitations

SimHydraulics performs transient analysis of hydro-mechanical systems. It may be able to use the higher-level library blocks, or it may need to build its actuators out of the lower-level library blocks. SimHydraulics is specifically developed to cover modeling scenarios with hydraulic actuators as part of a control system. It is also appropriate for systems that allow consideration in lumped parameters. [Mathworks2007]

SimHydraulics does not have the capability to model the following types of systems:

a) Fluid transportation
b) Water supply and sewer systems
c) Distributed parameters systems

SimHydraulics is based on the assumption that fluid temperature remains constant during the simulated time interval, and this temperature must be set as a parameter together with the relative amount of entrapped air. [Mathworks2007]

2.3.3 Basic Principles of Modeling Hydraulic Systems

Simscape provides the Physical Network approach for modeling and solving systems under design as one-dimensional networks. SimHydraulics utilizes these basic modeling principles and contains a library of specialized hydraulic blocks that seamlessly interact with basic Simscape blocks.SimHydraulics models are essentially Simscape block diagrams. When building a SimHydraulics model, it uses a combination of SimHydraulics blocks with the blocks from the Simscape Foundation and Utilities libraries. Each SimHydraulics diagram must have at least one Solver Configuration block from the Simscape Utilities library. It can use basic hydraulic, electrical, and one-dimensional translational and rotational mechanical elements from the Simscape Foundation library and directly connect them to SimHydraulics blocks. It can also use basic SIMULINK blocks, such as sources and scopes, but it need to connect them through the SIMULINK-PS Converter and PS-SIMULINK Converter blocks from the Simscape Utilities library. It can also use these converter blocks to specify the desired input and output signal units. [Mathworks2007]

CHAPTER 3
METHODOLOGY

3.1 WORKFLOW

This project has four major stages that have been completed which are:

a) Study and investigation on various subsea control system in SPS
b) Development of SPS SIMULINK model
c) Result analysis and observation
d) Improvement of SPS SIMULINK simulation system.

Figure 3-1 illustrates the overall project methodology of the project.

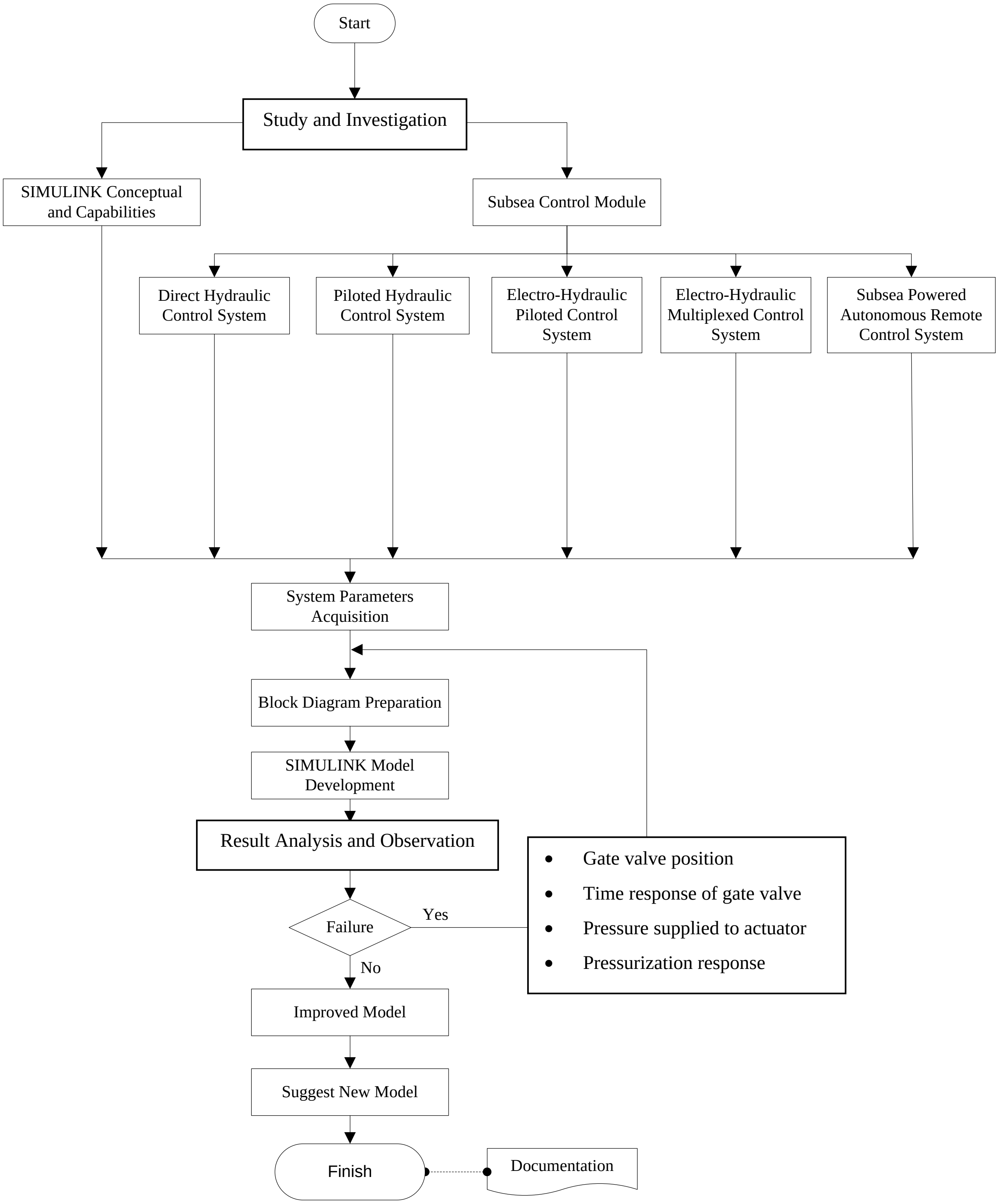

Figure 3-1: Flow Chart of the Project

3.2 STUDY AND INVESTIGATION ON SPS

In this stage, existing application of SPS principal operations are referred to and identified. SPS key design parameters acquisition, SIMULINK capabilities, SPS controls schematics, and advanced control SPS functions investigated by other research are the important highlights to be studied during this stage.

3.3 DEVELOPMENT OF SPS SIMULINK MODEL

After identifying the SPS parameters and the capability of the SIMULINK software, a basic SPS simulation model will be established. The basic simulation models of a suitable operation and specification will be developed with expected output of visual animation of fluid flow diagram. The main components of the model which consist of a typical completion and/or work over system for subsea wells are hydraulic power unit (HPU), umbilical, subsea control module (SCM), and valve actuator. Each of these components will be modelled in SIMULINK 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 software library.

3.3.1 Hydraulic Power Unit Model

During the modelling stage, HPU is modelled as shown in Figure 3-2 . The model has been developed based on the schematic diagram that has been established through literature review. 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. This is because all of the elements included in a model are include in the calculations, taking up part of the SIMULINK capacity.

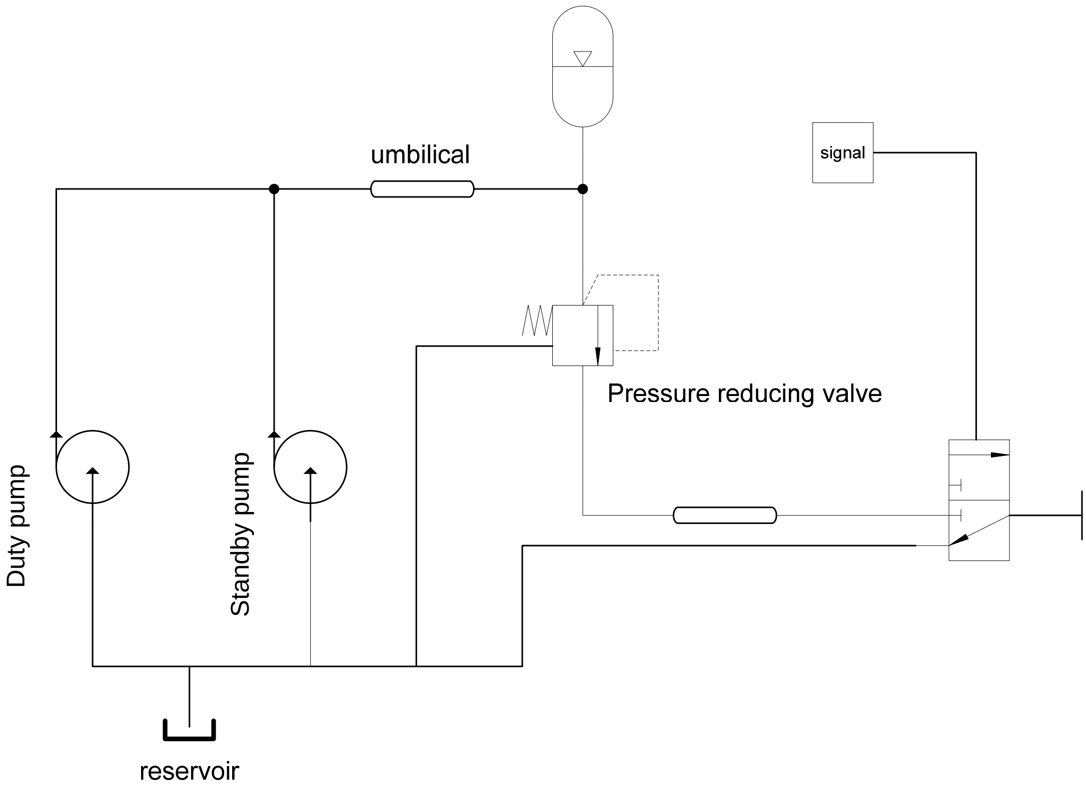

Figure 3-2: Hydraulic Power Unit Model Block Diagram. [Agito2008]

3.3.2 Distribution Line Model

For umbilical part, it is an advantage to use a distributed line model in which the line is split into several separate elements as shown in Figure 3-3. 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.

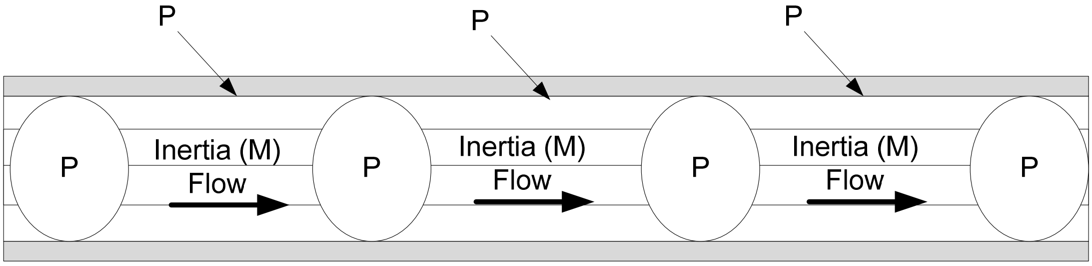

Figure 3-3: Distributed Line Model. [Agito2008]

3.3.3 Subsea Control Module Model

In modelling SCM, as previously mentioned, it is important to limit the number of elements in a model to the elements that are active in the sequences. In Figure 3-4 there is a SCM modelled in SIMULINK with the necessary number of valves, which is one.

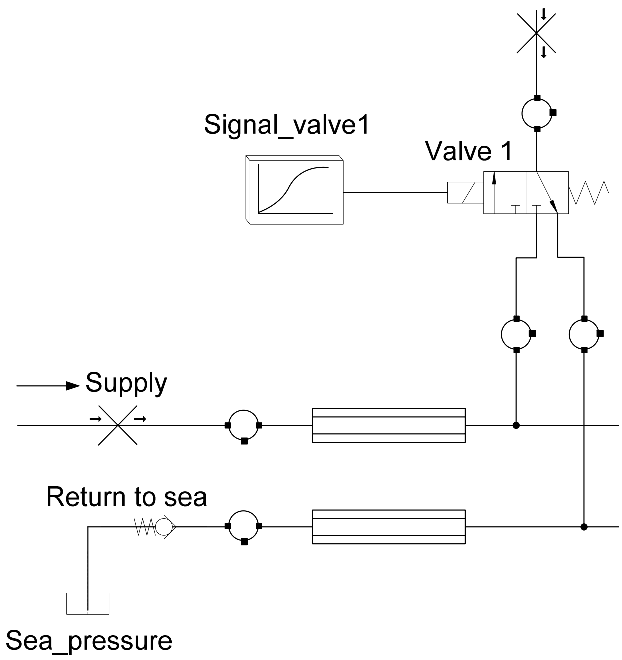

Figure 3-4: Subsea Control Module Model. [Agito2008]

3.3.4 Gate Valve Model

For valve actuator, it will be modelled 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 SIMULINK a typical model of a gate valve with an actuator will look in Figure 3-5.

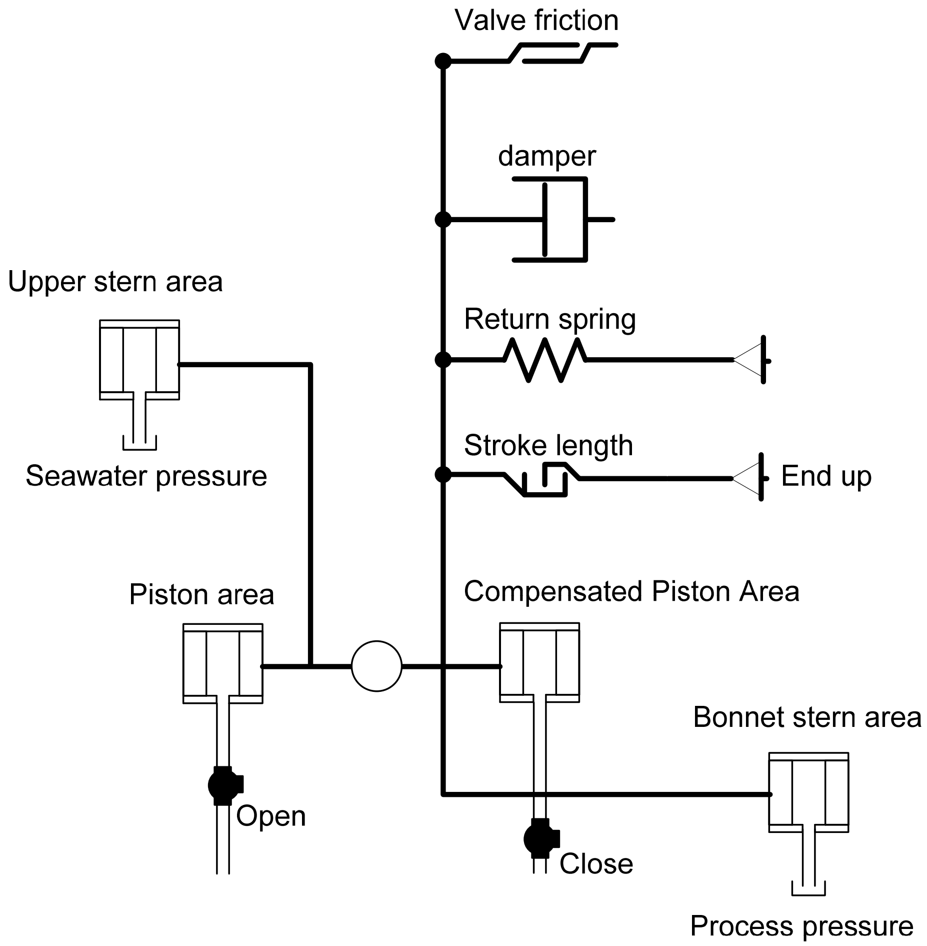

Figure 3-5: Gate Valve Model. [Agito2008]

So far defining all of the main components for a model of the complete system is almost done. What now remains are the actual parameters need to be identifying in order to achieve a real simulation of subsea production system.

3.4 RESULT ANALYSIS AND OBSERVATION

After the model has been developed with appropriate equation and sequences, it will be tested and analyzed by acquiring the output data. To ensure each element block diagram is properly developed, the output value of each block diagram will be compared with an analytical method using mathematical equation. Besides, a plot result of gate valve position and pressurization in actuator will be examined by comparing the output data with the actual parameter of the SPS principal operation, the successful of the simulation model will be determined. Further discussion is given in Chapter 4.

CHAPTER 4
SIMULINK MODEL DEVELOPMENT

4.1 HYDRAULIC POWER UNIT SIMULINK MODEL

Hydraulic Power Unit (HPU) is main element in direct hydraulic system. In order to simulate the element, the mathematical model and the transfer functions for the components have been developed. There are several assumptions involved, where functions of an accumulator and mass of the rotating equipment have been neglected. Since the equation and the SIMULINK diagram of the pump haven't done yet, it will be assumed that the supply pressure is constant and that the pump can always deliver the required amount of hydraulic fluid to the system. Thus, until now, the behavior of the pump does not need to be modeled. It is presumed that their contribution to the dynamics of the overall system is negligible. Hence, the supply pressure of the system will be indicated as p_s in SIMULINK block diagram.

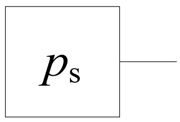

Figure 4-1: Constant Pressure Supplied in SIMULINK Block

4.2 SUBSEA CONTROL MODULE SIMULINK MODEL

SCM consists of directional valve which control the orifice area within the system. A SIMULINK diagram has been developed based on the orifice equation in the SCM. Orifices are sudden restrictions of short length (ideally zero length for a sharp-edged orifice) in the flow passage and may have a fixed or variable area. Orifices are generally used to control flow, or to create a pressure differential (valves) [Isermann2003].

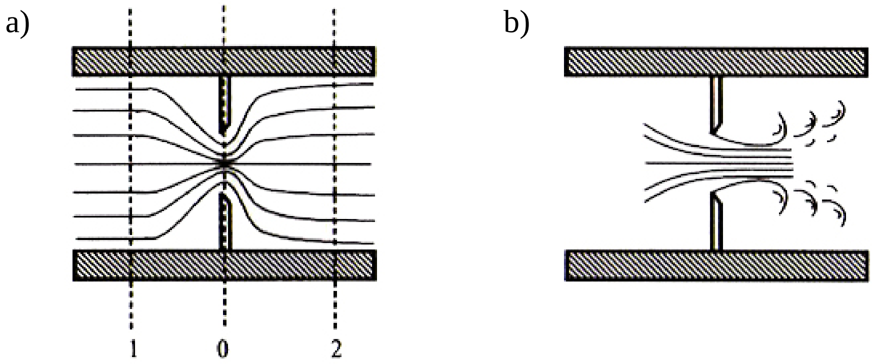

Figure 4-2: Flow through an orifice: (a) laminar flow; (b) turbulent flow [Jelali&Kroll2003].

Since most orifice flow occurs at high Reynolds numbers, this region is of major importance. According to Bernoulli's theorem, the total energy losses of the hydraulic flow are derived from the energy degraded into heat by friction of the particles against one another and by friction of the particles against the walls of the conduit [Arthur2006]. Referring to Figure 4-2a, the energy dissipated due to friction between sections 1and 2 will be equal to

$$\Delta p = \left(p_1 + \rho v_1^2/2 + \rho g z_1\right) - \left(p_2 + \rho v_2^2/2 + \rho g z_2\right) \quad (4.1)$$

It is common to use the dimensionless pressure loss factor ζ , which is defined as

$$\zeta = \frac{\Delta p}{\rho v_1^2/2} \quad \text{or} \quad \Delta p = \zeta \rho v_1^2/2 \quad (4.2)$$

The factor ζ , depends on the geometry of the conduit and on the Reynolds number which can be approximated by

$$\zeta(\mathrm{Re}) = \frac{k_1}{\mathrm{Re}} + k_2 \quad (4.3)$$

Taking into account that at a point far from the orifice

$$v_1 = v_2 = v \quad \text{and} \quad A_1 = A_2 = A = \frac{\pi}{4} d^2 = \text{constant} \quad (4.4)$$

Given the flow as the product of conduit area and the speed, *i.e.*,

$$Q = Av = A\sqrt{\frac{2}{\rho\zeta}\left(p_1 - p_2\right)} \quad (4.5)$$

Instead of Equation 3.5, it is common in the field of hydraulics to use the modified orifice equation

$$Q = C_d A \sqrt{\frac{2}{\rho} \Delta p} \tag{4.6}$$

Where C_d is the discharge coefficient. Theoretically, $C_d = \pi / (\pi + 2) = 0.611$ [vonMises1917]. This can be used for all sharp-edged orifices regardless of the particular geometry, if the flow is turbulent and $A_0 << A$. From the equation above, turbulent flow through the directional valve with the orifice equation can be modeled. However, the problem occurs because the term Δp may reverse its sign. Computer programming language object to finding the square root of a negative number. The problem is easily solved by introducing a multiplying factor on the right-hand side of the coded equation. This factor, here called SIGN, will be -1 if Δp is negative, 0 if Δp is zero, and +1 if Δp is positive. Now flow direction has been associated with SIGN, Δp is replaced by $|\Delta p|$ in the coded equation [Arthur2006].

$$Q = C_d . A \sqrt{\frac{2}{\rho} |\Delta p|} \,.\, SIGN(p_1 - p_2) \tag{4.7}$$

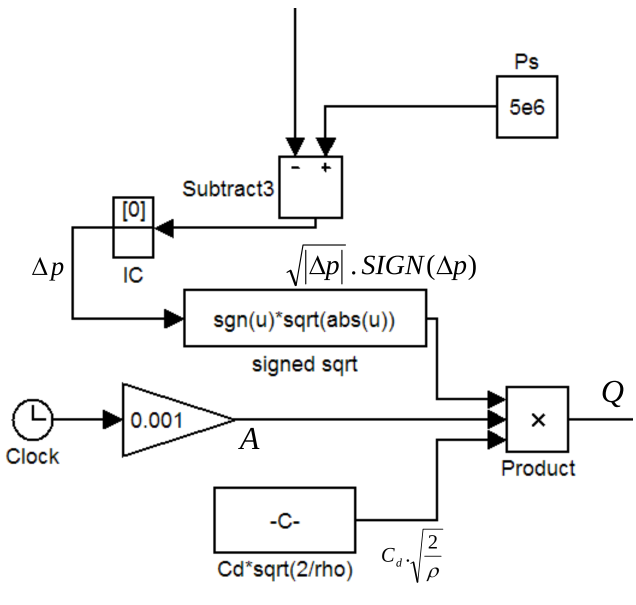

Figure 4-3: Directional Valve with Control Orifice SIMULINK Block

Referring to Figure 4-3, the SIMULINK block has been developed based on equation 4.7. The input of the block should be pressure difference $|\Delta p|$, orifice area *A*, fluid density ρ , and discharge coefficient C_d while the output of the block is the volume flow rate *Q*, of the hydraulic fluid passes through the orifice in the directional valve.
For orifice area *A*, the input value will be gained about 0.001m^2 every time step taken until it is fully open. The area of the orifice is controlled by the operator on the platform where simply push a button to switch the orifice area to start open from time t=0 until t=10 second. To ensure the control orifice SIMULINK block is properly developed, the output value *Q* will be compared with an analytical method where it is assumed that the input value of the pressure difference Δp, is equal with pressure supplied p_s.
The value of each parameter will be given on table below:

Table 4-1: Key parameters for subsea control module

Parameter	**Value**
Orifice discharge coefficient, C_d	0.61
Fluid density, ρ	800 kg/m^3
Orifice area, A	$t_{0.1}$= 0.0001 m^3 ; $t_{0.2}$= 0.0002 m^3
Pressure supplied, P_s	5 Mpa

At time t=0.1, the volume flow rate, Q;

$$Q = C_d . A\sqrt{\frac{2}{\rho}|\Delta p|} \, . SIGN(p_1 - p_2)$$

$$Q = 0.61*(0.1*0.001)\sqrt{\frac{2}{800}*5e6}$$

$$Q = 0.0068 \ \text{m}^3\text{/s}$$

At time t=0.2, the volume flow rate, Q;

$$Q = 0.61*(0.2*0.001)\sqrt{\frac{2}{800}*5e6}$$

$$Q = 0.0136 \ \text{m}^3\text{/s}$$

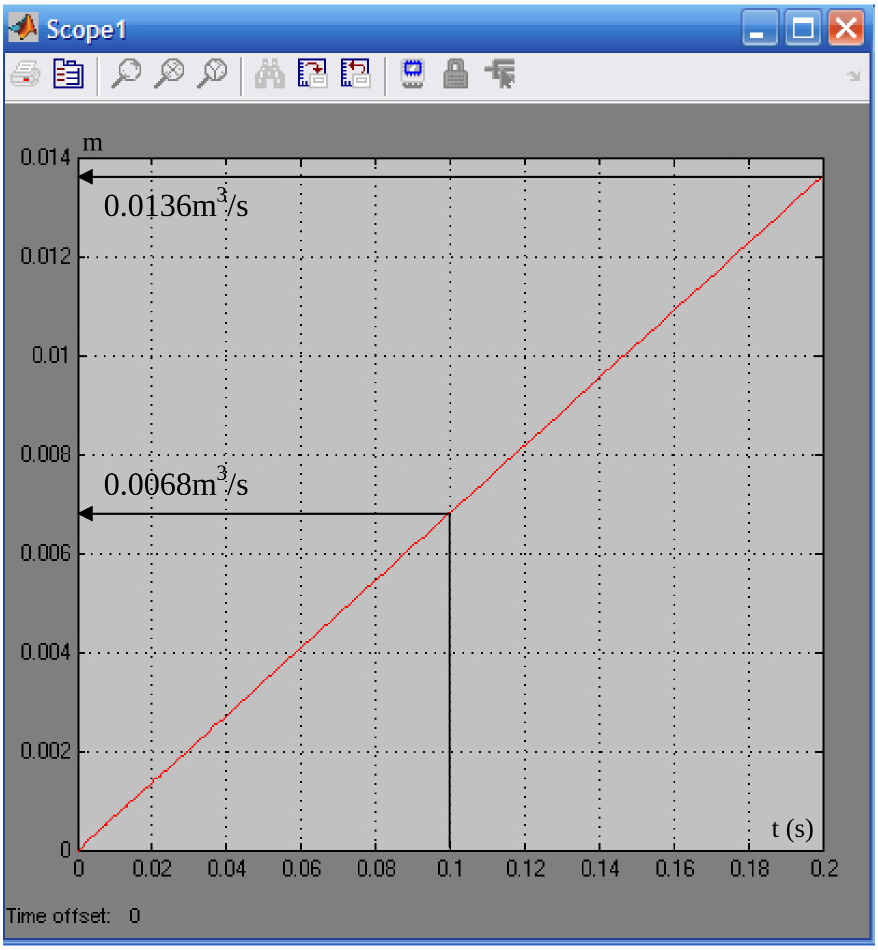

Figure 4-4: Orifice area plot result

4.3 PHYSICAL PROPERTIES OF FLUID

Fluids are bodies without their own shape; they can flow. i.e., they can undergo great variations of shape under the action of forces; the weaker the force, the slower the variation. The normal tension on the surface element of a fluid is called *pressure* [Jelali&Kroll2003]. It is, at a given point, identical in all direction. Pressure can be calculated as

$$p = \frac{\text{Force}}{\text{Area}} = \frac{F}{A} \tag{4.8}$$

and thus has the dimensions of force per unit area (N/m^2). Physical properties of the hydraulic fluid and surrounding vessels play an important role in the overall performance of hydraulic control systems. The equation of state relates by definition the pressure, temperature, and density of any solid, liquid, or gaseous phase. In general, when a change in pressure is applied to a fluid volume, a volume change occurs [Isermann2003]. Therefore, in order to develop a simulation, this effect cannot be neglected. The relation between these quantities is called the *bulk modulus* or *compressibility module* which is defined as

$$\beta = -V\left(\frac{\Delta p}{\Delta V}\right) \tag{4.9}$$

The compressibility κ of a liquid is defined by

$$\kappa = \frac{1}{\beta} = -\frac{1}{V}\left(\frac{\Delta V}{\Delta p}\right) \tag{4.10}$$

The compressibility is not only affected by the fluid itself. It is also altered by air trapped in the liquid. Further, if thin-walled vessels are pressurized, then these vessels will expand as their walls give way [Isermann2003]. This increases the volume that the enclosed liquid can fill and thus causes a decrease in both pressure and density of the encompassed fluid. This interaction also effectively changes the bulk modulus.

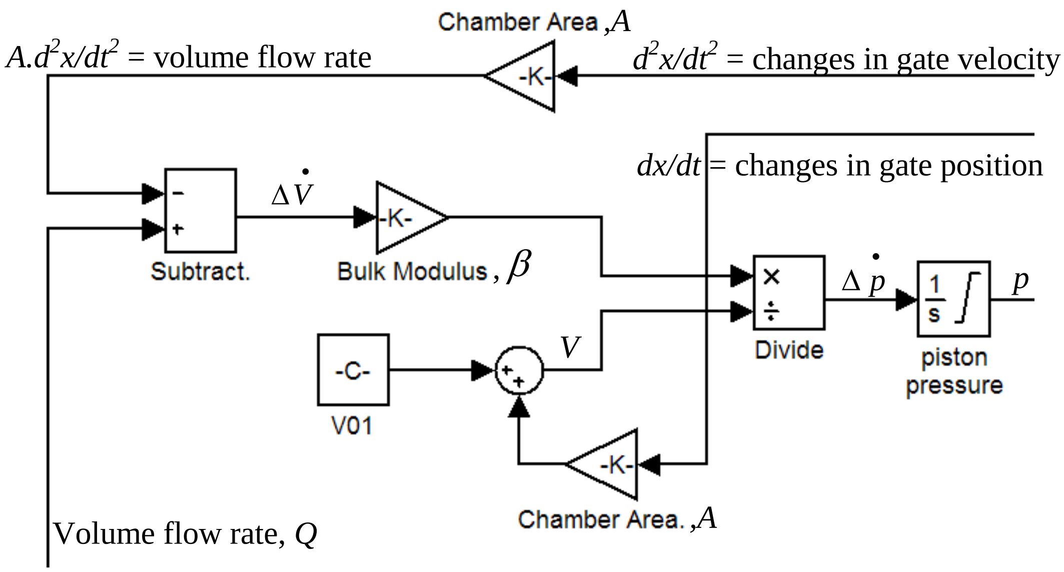

Figure 4-5: Fluid Compressibility SIMULINK Block

Referring to Figure 4-5, the SIMULINK block has been developed based on equation 4.9 where $\Delta p = \int \Delta \dot{V} \beta / V$ .The input through the block should be bulk modulus β , fluid volume flow rate *Q*, and the current volume *V*, of the fluid in the chamber while the output of the block is the total supplied pressure *p*, to the actuator. To ensure the block diagram is properly installed, the output pressure *p*, will be compared with an analytical data where it is assumed that the changes in gate position and velocity has been neglected. Besides, the input value of the volume flow rate *Q*, will be based on Figure 4-4. The value of each parameter will be given on Table 4-2: Key parameters for fluid compressibility

Table 4-2: Key parameters for fluid compressibility

Parameter	**Value**
Bulk modulus, β	700 Mpa
Fluid Volume, V	2.5x10^{-5} m^{3}
Chamber area, A	1x10^{-3} m^{2}

At time t=0.1, the output pressure, *p*;

$$\Delta \dot{p} = \Delta \dot{V}\, \beta / V$$

$$\Delta \dot{p} = \frac{0.0068\,\text{m}^3/\text{s} * 700\,\text{Mpa}}{2.5\times10^{-5}\,\text{m}^3} = 1.904\times10^{11}$$

$$p = \beta / V \int \Delta \dot{V}$$

$$p = \beta / V \int 0.068 t^2 dt$$

$$p = \beta / V \left[0.068 t^2 / 2\right]^{t\sim0.1}$$

$$p = \frac{700\,\text{Mpa}}{2.5\times10^{-5}\,\text{m}^3}\left[0.068 * 0.1^2 / 2\right] = 0.952\times10^{10}\ \text{Pa}$$

For time t=0.2, the output pressure, *p*;

$$\Delta \dot{p} = \Delta \dot{V}\, \beta / V$$

$$\Delta \dot{p} = \frac{0.0136\,\text{m}^3/\text{s} * 700\,\text{Mpa}}{2.5\times10^{-5}\,\text{m}^3} = 3.808\times10^{11}$$

$$p = \beta / V \int \Delta \dot{V}$$

$$p = \beta / V \int 0.068t^2 dt$$

$$p = \beta / V \left[0.068t^2 / 2 \right]^{t\sim0.2}$$

$$p = \frac{700\,\text{Mpa}}{2.5\times10^{-5}\,\text{m}^3}\left[0.068 * 0.2^2 / 2\right] = 3.808\times10^{10}\ \text{Pa}$$

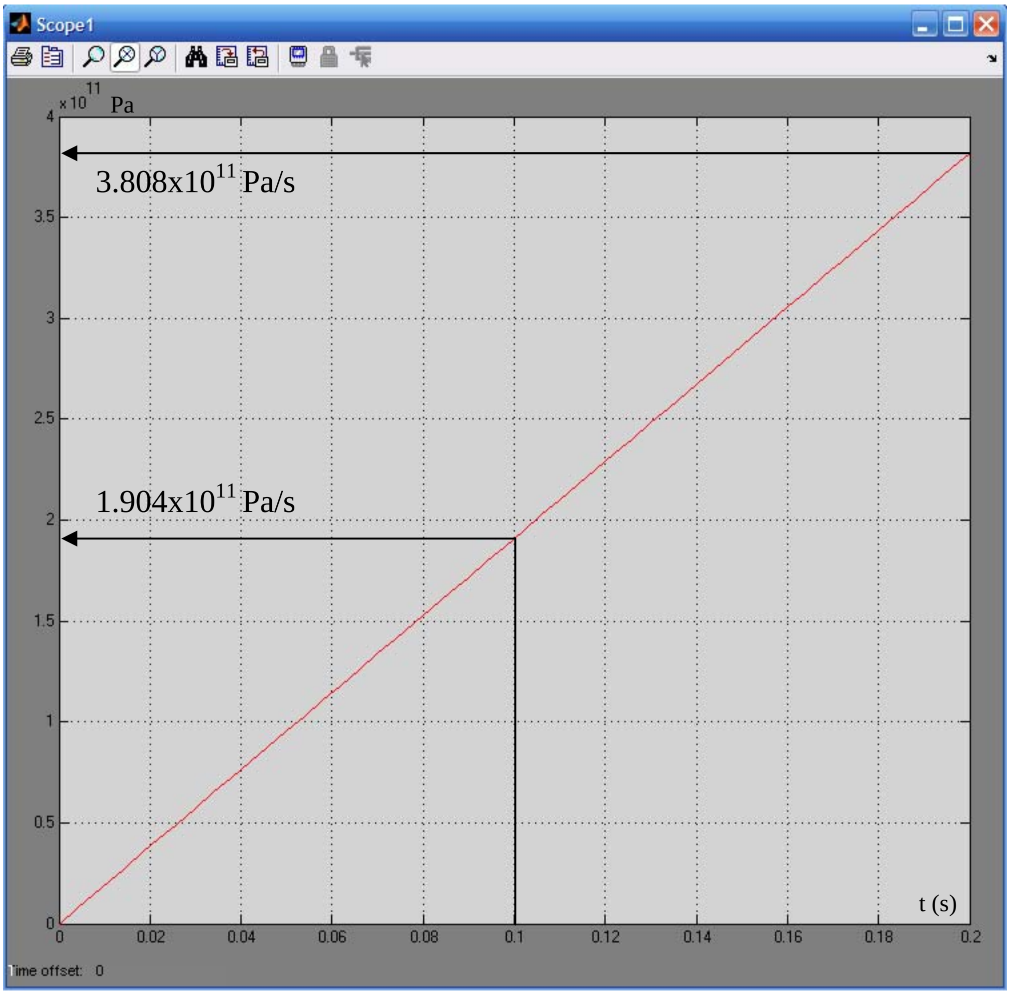

Figure 4-6: Plot of pressure rate, $\dot{p}$ in chamber

Referring to Figure 4-6, a pressure rate in the directional valve is proportional increase with time. At time t=0.1, the pressure rate increase at $1.904\text{x}10^{11}$ Pa/s where it gave a same value with an analytical method. Same with pressure rate at t=0.2, the value of $3.808\text{x}10^{11}$ Pa/s is identical with the analytical method. Hence, it will proved that the SIMULINK block diagram of fluid compressibility has been properly installed just before the integral of the pressurization rate.

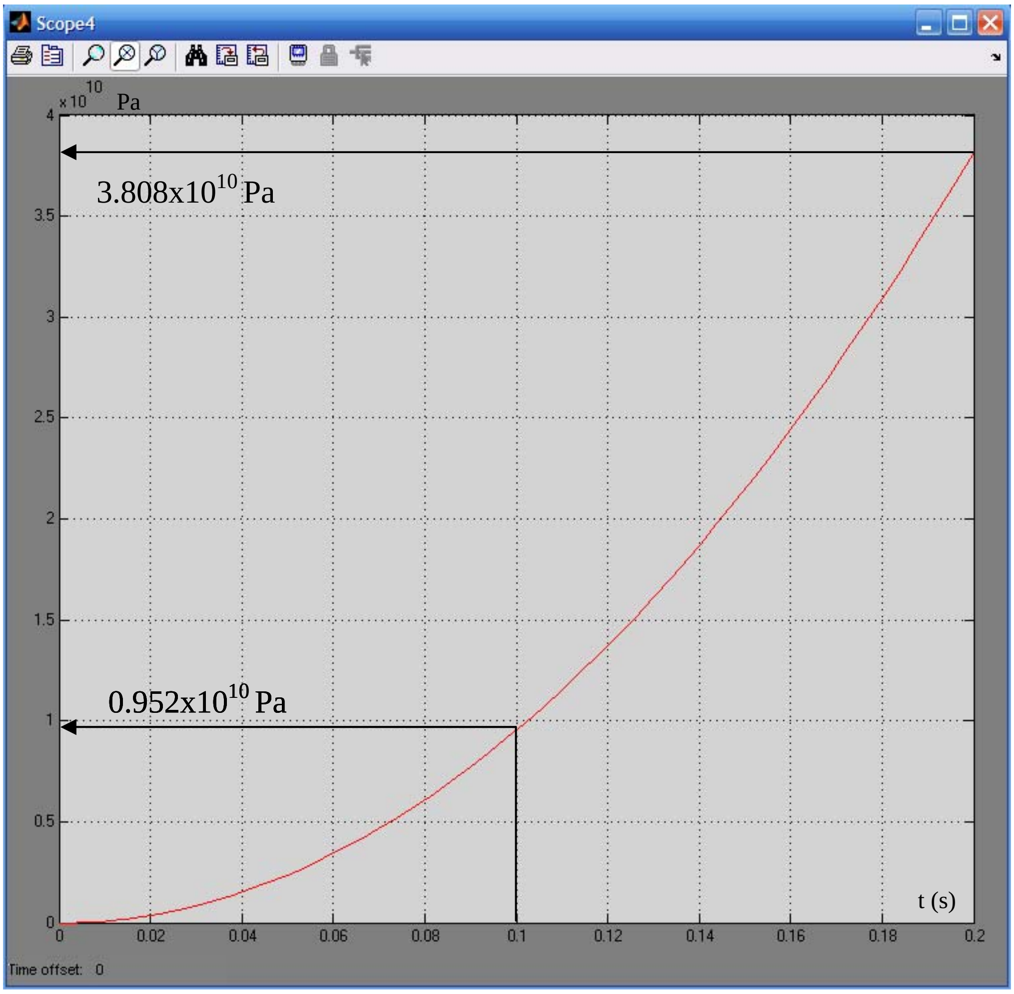

Figure 4-7: Plot of pressure, *p* in chamber

Referring to Figure 4-7, a pressurization in the directional valve is proportional increase with time. At time t=0.1, the pressurization increase at 0.952×10^{10} Pa where it gave a same value with an analytical method. Same with pressurization at t=0.2, the value of 3.808×10^{10} Pa is identical with the analytical method. Hence, it will prove that the SIMULINK block diagram of fluid compressibility has been properly installed just after the integral of the pressurization rate.

4.4 VALVE ACTUATOR SIMULINK MODEL

Valve actuator in subsea production system is devices to convert hydraulic energy provided by the pump and processed by the control elements (i.e., valves) into useful work and consequently into power and mechanical energy respectively. It used to convert hydraulic power into linear mechanical force or motion in order to open the gate valve and allow an oil and gas to flow through the tree.

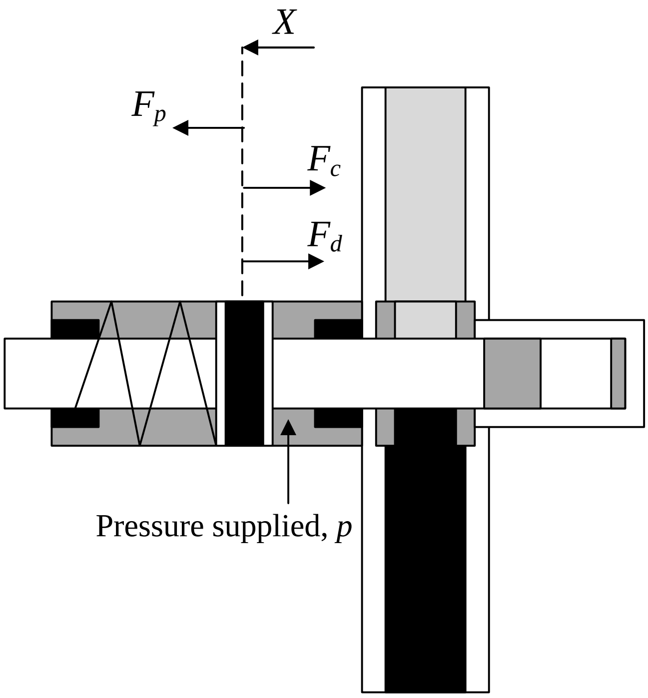

Figure 4-8: Actuator with excitation by forces Gate Valve Model. [Agito2008]

Referring to Figure 4-8, an external force *Fp* which is from pressure supplied, *p* exerts to a piston causes it to move and open the gate valve. The force *Fp* can be written using the principle of linear momentum as [Jelali&Kroll2003]

$$m\ddot{X}_0(t) = F_p(t) - F_c(t) - F_d(t) \qquad (4.11)$$

Applying the constitutive equation of the spring leads to

$$F_c(t) = cX_0(t)$$

and applying the phenomenological equation to the damper yields

$$F_d(t) = d\,\dot{X}_0(t)$$

Insertion into Equation 4.11 results in

$$m\,\ddot{X}_0(t) = F_p(t) - cX_0(t) - d\,\dot{X}_0(t) \tag{4.12}$$

Now, changes $X = \Delta X = X - X_0$ and $\Delta F_p = F_p(t) - F_p$ around this equilibrium state are considered. This leads to

$$m\,\ddot{X}_0(t) + d\,\dot{X}_0(t) + cX_0(t) = \Delta F_p(t) \tag{4.13}$$

If Equation 4.13 is written in the form

$$m\,\ddot{X}_0(t) = -cX_0(t) - d\,\dot{X}_0(t) + \Delta F_p(t)\,.$$

then the block diagram according to Figure 4-9 results for the input $\Delta F_p(t)$. This is the elementary block diagram of the spring –mass-damper system in serial configuration. It directly follows from the differential equation for the principle of linear momentum, the constitutive equation for the spring and the phenomenological equation for the damper.

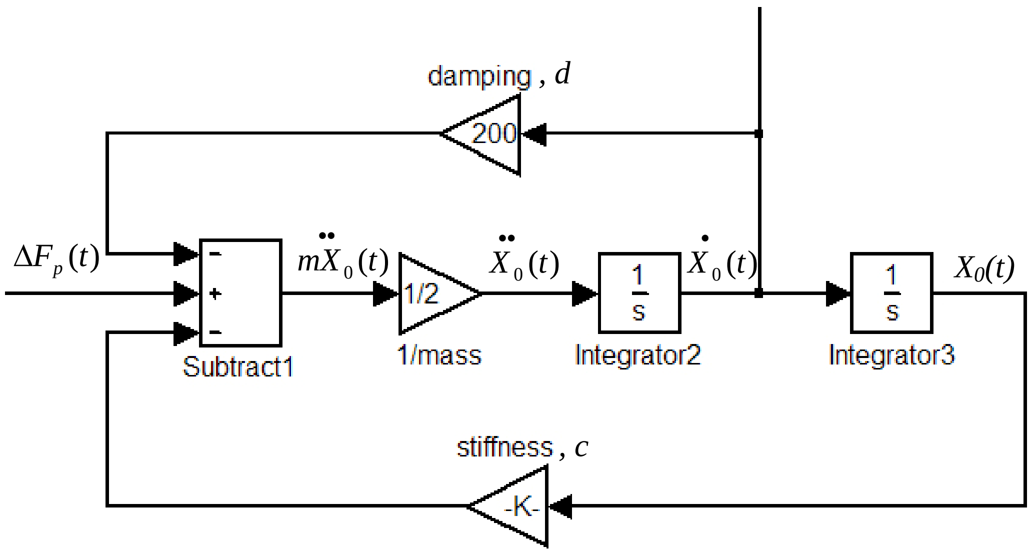

Figure 4-9: SIMULINK block diagram of the gate valve actuator

4.5 TYPICAL DIRECT HYDRAULIC CONTROL SIMULINK MODEL

Combination of all components diagram would lead to model the typical direct hydraulic control system. FIGURE 4-10 shows the overall SIMULINK diagram that has been developed based on the physical model and respective equation.

CHAPTER 5
RESULT AND DISCUSSION

5.1 SIMULATION RESULT AND DISCUSSION

After the simulation system is developed and executed, the results of the simulation are shown in Figure 5-1 and Figure 5-2 below where it illustrate a pressure supplied through the actuator and position of the gate valve within 0.1 seconds respectively.

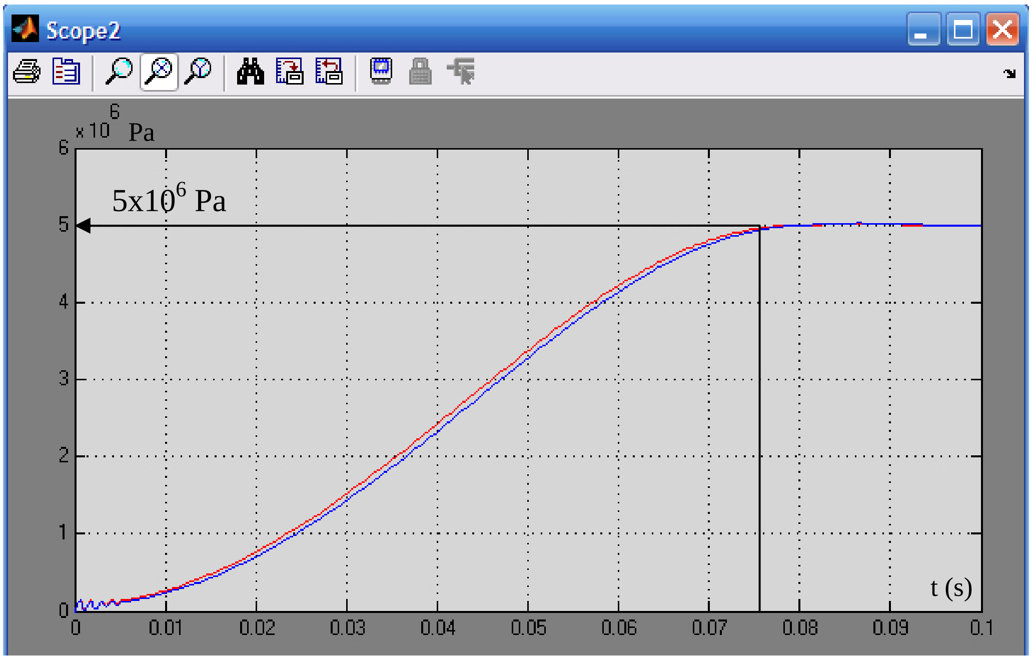

Figure 5-1: Plot result of simulated transient function of a pressure supplied through the actuator.

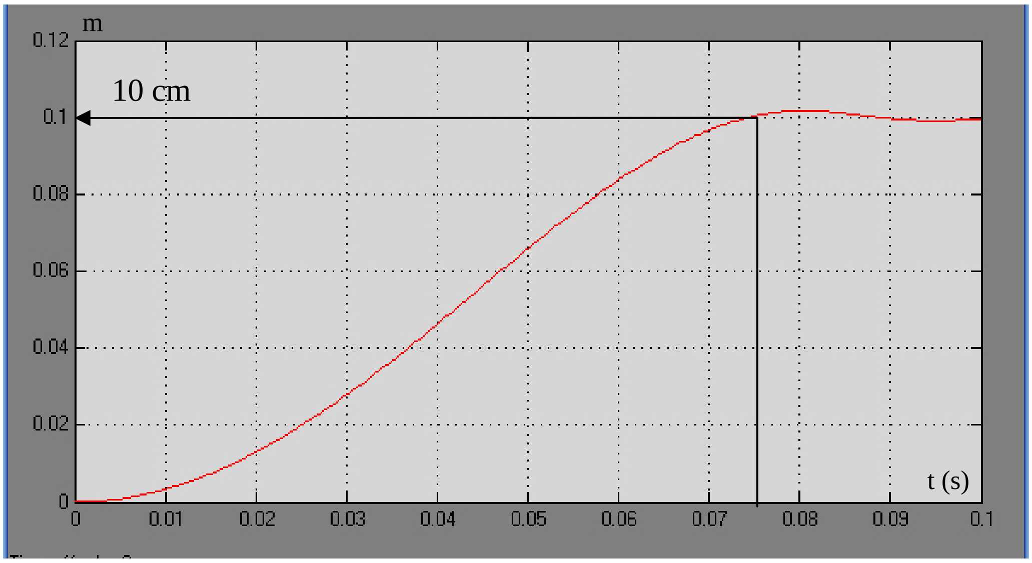

Figure 5-2: Plot result of simulated transient function of the position of the gate valve.

Referring to Figure 5-1 and Figure 5-2, a movement of the gate valve and pressurization in the actuator can be monitored. The control valves starts with zero orifice area and ramps to 1x10-4 m2 during the 0.1 second simulation time. As the directional valves opens, pressure build up to supplied force to the actuator. The actuator position is directly proportional to the pressure supplied, where the hydraulic and spring forces balance. The model reaches, a steady state when all of the pump flow again goes to leakage, now due to zero pressure drop across the directional valves. It can be seen that the gate valve move to fully open at 10cm within 0.075s.

5.2 SENSITIVITY ANALYSIS RESULT AND DISCUSSION

Sensitivity analysis is a measure of sensitivity when one of the parameter of the system varies. There are three parameters selected which are supplied pressures, mass of actuator, and spring stiffness.

5.2.1 Sensitivity analysis on manipulated supplied pressure

For this analysis, the constant parameters are discharge coefficient, fluid density, fluid compressibility, mass of actuator, and spring stiffness while the pressure supply being manipulated in order to test the sensitivity of the system.

Table 5-1: Constant parameter table for manipulated supplied pressure

Parameter	**Value**
Cd	0.61
Fluid density	800 kg/m^3
Fluid Compressibility	700 Mpa
Mass of actuator	1 kg
Spring Stiffness	$5x10^4$ N/m

Table 5-2: Various pressure supply effect time taken for a gate valve to fully open

Supplied Pressure (Mpa)	**Time taken for a gate valve to fully open**
10	0.088 s
12	0.074 s
14	0.068 s
16	0.064 s
18	0.061 s
20	0.059 s
22	0.057 s
24	0.056 s

Referring to table 5-2, time taken for a gate valve to fully open is increasing when the supplied pressure increased. According to law of motion, when pressure increased while the contact area is constant, the force acting on the piston will increase. Hence, the velocity of the piston will increase. As a result, the time taken for a gate valve to fully open is reduced.

5.2.2 Sensitivity analysis on manipulated actuator mass

For this analysis, the constant parameters are discharge coefficient, fluid density, fluid compressibility, supplied pressure, and spring stiffness while the mass of actuator being manipulated in order to test the sensitivity of the system.

Table 5-3: Constant parameter table for manipulated mass of actuator

Parameter	Value
Cd	0.61
Fluid density	800 kg/m^3
Fluid Compressibility	700 Mpa
Supplied Pressure	10 Mpa
Spring Stiffness	$5x10^4$ N/m

Table 5-4: Various mass of actuator effect time taken for a gate valve to fully open

Actuator Mass (kg)	Time taken for a gate valve to fully open
1	0.088 s
100	0.093 s
150	0.103 s
200	0.110 s
250	0.116 s

For sensitivity analysis on manipulated mass of the actuator, time taken for a gate valve to fully open is increasing when the mass of the actuator increased. This is because required force exerts to the actuator is higher due to high load of the actuator.

5.2.3 Sensitivity analysis on manipulated spring stiffness

For this analysis, the constant parameters are discharge coefficient, fluid density, fluid compressibility, supplied pressure, and supplied pressure while the spring stiffness being manipulated in order to test the sensitivity of the system.

Table 5-5: Constant parameter table for manipulated spring stiffness

Parameter	Value
Cd	0.61
Fluid density	800 kg/m^3
Fluid Compressibility	700 Mpa
Mass of actuator	1 kg
Pressure supply	10 Mpa

Table 5-6: Various spring stiffness effect time taken for a gate valve to fully open

Spring Stiffness (N/m)	Time taken for a gate valve to fully open
0.1x10^4	0.064 s
0.5x10^4	0.065 s
0.9x10^4	0.066 s
1x10^4	0.067 s
2x10^4	0.069 s
3x10^4	0.072 s
4x10^4	0.076 s
5x10^4	0.088 s

Referring to table 5-6, time taken for a gate valve to fully open is increasing when the spring stiffness increased. Stiffness is a measure of how well an actuator can hold a position when some outside force is trying to move it. The stiffness of a spring is determined by how much force it takes to compress it a unit of distance. Stiffness is one of the more subtle specifications in a control system and is often overlooked, but it can have a major impact on accuracy in the face of load disturbances.

The sensitivity analysis proves that the simulation system is sensitized when key parameters are varied. Hence, the simulation is useful to conduct a sensitivity analysis in the matter of SPS changing key design parameters such as supplied pressure, mass of actuator, and spring stiffness.

CHAPTER 6

CONCLUSION AND RECOMMENDATION

6.1 CONCLUSION

The objectives of this project had been achieved. Both objectives are to develop a SIMULINK model for a specific SPS and simulate the control module functions that govern the associated SPS operations. A development of simulation system for a typical direct hydraulic control system will fulfill the oil and gas industry needs where an analysis and observation can be made during its design stage. For example, a movement of the gate valve can be observed and analyzed in SIMULINK simulation system in order to meet the SPS design specification before it can be use.

Based on the result and discussion, it can be concluded that the typical direct hydraulic simulation system has been done properly and need further improvement. Throughout the simulation, a sensitivity analysis can be done by examined the movement of the gate valve due to changes of their key design parameters such as supplied pressure, mass of actuator, and spring stiffness.

In designing subsea production system, it should be as simple and straightforward as possible and still meet requirements for operational considerations and the physical layout of the field. System reliability, maintainability, control response times, and valve position to the operator are some of the most important factors that must be considered. Physical aspects of the oilfield-water depth, lateral offset of the subsea equipment from its associated platform, anticipated sea or ice conditions, and the potential for well damage caused by shut-ins and the complexity of the subsea facility determine the optimal design of the control system.

6.2 RECOMMENDATION

There are certain limitations in the developed simulation system:

- A one directional valve (i.e non-returning valve) is used since a bi-directional valve was not able to be formulated within the time limitation due to its complexity.
- This simulation only operates for 1 second and it cannot be extend for a longer interval.
- This simulation doesn’t involve nonlinear characteristics which may involve effects of fluid inertia and backlash.
- This simulation doesn’t include transfer function of each element to show the relations between input and output of the parameters.

Therefore, recommendation for further work may include the following:

- Develop a more comprehensive SIMULINK control equation and transfer functions hence a model that enables bi-directional valve opening and closure with an extended operational interval time, show the relation between input and output of the parameters, and ability to simulate non-linear characteristics.

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APPENDICES