

**BRITISH FLUID POWER  
ASSOCIATION  
QUALIFICATIONS**

**HYDRAULIC SYSTEM DESIGN  
PROGRAMME (HSD4)**

**CETOP (PASSPORT) OCCUPATIONAL  
LEVEL 4**

## FOREWORD

Developed by the BFPA Education and Training Committee, this programme represents one of a range of new qualifications launched by BFPA.

The HSD4 programme provides an excellent foundation of knowledge for those people whose occupational role involves or is likely to involve in the future, hydraulic system design, alterations and improvements to existing systems

The aim of the programme is to provide candidates with a thorough understanding of the Principles of Hydraulic System Design and the “step by step” procedures to follow when planning any design or re-design project.

The programme involves the acquisition of both competence based and knowledge-based skills which are designed to be complimented throughout by the candidate’s own work place experience.

Calculation and formulae will be used extensively throughout and a strong emphasis will be placed upon the use of manufacturers’ technical data when configuring a solution to a design problem.

The programme will include a thorough investigation of the system design process from the formulation of the application specification to component selection, circuit design and systems management.

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**PRIOR KNOWLEDGE/ EXPERIENCE (Recommended Entry Level)**

- Engineering HNC and/or A-Level Mathematics (or Equivalent Qualifications)
- Understanding of Engineering Principles and processes
- An understanding of the operation of hydraulic systems and components

**NOTE: Final selection of candidates will be at the discretion of the Approved Centre.**

**Methodology and Assessment**

The programme can be offered via a range of learning modes devised by the approved centres but it is envisaged that distance learning supported by a series of centre based modules will be the normal system used.

Candidates will be expected to complete a series of assignments throughout the programme of study to reinforce the learning process. Final assessment will be via an integrated system design project involving both knowledge and competence based skills. This project will contribute 50% of the final marks with a written examination of 3 hours duration representing the remainder.

The overall minimum pass mark to acquire this qualification will be 70% but candidates must achieve at least 60% marks for both the project and the examination.

The expected completion time for this competence base programme is 1-2 years and will require a high level of personal commitment to study and research the subjects within the syllabus.

## **PROGRAMME CONTENTS**

### **SECTION A**

#### **COMPETENCE BASED**

|        |                                      |
|--------|--------------------------------------|
| HSD4.1 | Application and System Specification |
| HSD4.2 | Circuit Design                       |
| HSD4.3 | Component Selection                  |
| HSD4.4 | Control System Design                |
| HSD4.5 | System Performance Evaluation        |
| HSD4.6 | Systems Management/Configuration     |

### **SECTION B**

#### **KNOWLEDGE BASED**

Providing underpinning knowledge to support competence based modules.

|         |                               |
|---------|-------------------------------|
| HSD4.7  | Application Specification     |
| HSD4.8  | Circuit Design                |
| HSD4.9  | Component Selection           |
| HSD4.10 | Control System Design         |
| HSD4.11 | System Performance Evaluation |
| HSD4.12 | Systems Management            |

**NOTE: Practical laboratory sessions will be included to enable candidates to investigate both component and system performance, thereby relating theory to practice.**

**HYDRAULIC SYSTEM DESIGN (HSD4)****COMPETENCE BASED MODULE HSD4.1 – Application and System Specification****Assessed Ability****HSD4.1 Establish system specification to meet the application specification****Evidence Required**

HSD4.1.1 Prepare system specification to include:

- a) Actuator sizes relating to force, torque and speed requirements.
- b) Pressure-Time/Flow-Time diagrams relating to associated duty cycle or machine operation.
- c) Draft circuit or box-line layout/options.
- d) Outline of control considerations/options.
- e) Constraints.
- f) Site/machine layout.
- g) Available services.
- h) Systems management.

HSD4.1.2 **Provide relevant information and possible solutions to meet the specification including:**

- a) Sufficient detail to enable effective consideration by others.
- b) A clear rationale for the solutions recommended, detailing the expected benefits.
- c) Implications of implementing the recommended solutions.

Note: Recommendations must be presented clearly and in a manner which supports decision making.

**COMPETENCE BASED MODULE HSD4.2 – Circuit Design****Assessed Ability****HSD4.2 Prepare suitable circuitry to meet the system specification****Evidence Required**

- HSD4.2.1 Design circuitry to meet the system specification.
- HSD4.2.2 Draw all schematic circuits using symbols to relevant ISO standards.
- HSD4.2.3 Justify the reason(s) for selection of the recommended circuit.
- HSD4.2.4 Ensure that all design documentation is appropriately collated into a technical file.

**COMPETENCE BASED MODULE HSD4.3 - Component Selection****Assessed Ability****HSD4.3**      **Select components to meet system specification****Evidence Required**

- HSD4.3.1      Select relevant components from Manufacturers' Technical Data.  
HSD4.3.2      Establish relevant model code numbers.  
HSD4.3.3      Justify component selection.

**COMPETENCE BASED MODULE HSD4.4 - Control System Design****Assessed Ability****HSD4.4**      **Establish a suitable control system to meet the specification****Evidence Required**

- HSD4.4.1      Evaluate the performance of typical open and closed loop control systems using appropriate data.  
HSD4.4.2      Prepare a proposed layout for the hydraulic circuit control system incorporating the essential features to meet the required specification, relating to:  
                    - accuracy  
                    - repeatability  
                    - response  
                    - stability  
                    - efficiency  
                    - ease of use  
                    - cost

**COMPETENCE BASED MODULE HSD4.5 - System Performance Evaluation****Assessed Ability****HSD4.5**      **Establish that the design performance meets the design specification****Evidence Required**

- HSD4.5.1      Describe the performance characteristics of the overall system under the specified operating conditions with respect to:  
a)      output power  
b)      output torque/force  
c)      output speed  
d)      system efficiency

**COMPETENCE BASED MODULE HSD4.6 - Systems Management/Configuration****Assessed Ability****HSD4.6**      **Establish the necessary systems management to meet the specification****Evidence Required**

HSD4.6.1      Identify the system requirements in terms of test and monitoring equipment.

HSD4.6.2      Identify suitable locations for test and monitoring equipment.

HSD4.6.3      Select appropriate equipment to meet the specification.

HSD4.6.4      Prepare procedures relating to:

- Installation
- Commissioning
- Routine condition monitoring
- Maintenance
- Fault finding
- Safety

**HYDRAULIC SYSTEM DESIGN (HSD4)****KNOWLEDGE BASED MODULE HSD4.7 - Application Specification**HSD4.7.1      Identify the nature of the load to be moved by applying engineering principles to establish the effective load acting on the actuator output, arising from the effects of:

- i)      mass and inertia
- ii)     friction
- iii)    gravity
- iv)    other external forces

**NOTE:** Effective load takes into consideration any transmission mechanism between the actual load and the actuator output shaft.

HSD4.7.2      Prepare a diagram representing the system/machine duty cycle/operational sequence using the velocity – time relationship.HSD4.7.3      Calculate the force/torque and velocity during a specified machine operation.HSD4.7.4      Identify the constraints/requirements to be considered as part of the design project with reference to:

- a)      environment
- b)      commercial considerations
- c)      physical attributes
- d)      safety/legislative requirements
- e)      customer specification

HSD4.7.5 Describe the layout/services to be considered with reference to:

- a) electrical supply
- b) water supply
- c) loading and lifting facilities
- d) storage facilities
- e) proposed location and necessary preparation
- f) maintenance and service facilities

HSD4.7.6 Determine actuator sizes taking into consideration:

- a) mechanical strength
- b) system pressure
- c) stroke
- d) space availability
- e) force, torque and speed
- f) system flow
- g) nature of load

**NOTE:** Full use should be made of manufacturers' catalogues, associated formulae and calculations.

HSD4.7.7 Construct pressure/time, flow/time and pressure/flow diagrams to meet specification.

HSD4.7.8 Analyse and optimise actuator sizes from information derived from HSD4.7.6.

HSD4.7.9 Analyse and optimise control valve combinations.

HSD4.7.10 Analyse and optimise the hydraulic power supply relating to systems incorporating:

- a) Fixed 'P' and Fixed 'Q'
- b) Fixed 'P' and Variable 'Q'
- c) Variable 'P' and Variable 'Q'
- d) Variable 'P' and Fixed 'Q'

**KNOWLEDGE BASED MODULE HSD4.8 - Circuit Design**

HSD4.8.1 Describe the systems/methods used to achieve actuator control with respect to:

- a) **Position referring to:**
  - (i) Pilot operated check valves
  - (ii) Closed loop control
  - (iii) Direction control valves
  - (iv) Brakes
  - (v) Load holding valves
  
- b) **Velocity referring to:**
  - (i) Throttling mechanisms
  - (ii) Pressure compensated flow control valves
  - (iii) Flow dividers
  - (iv) Parallel pumps/motors
  - (v) Variable displacement pumps
  - (vi) Variable speed pumps
  - (vii) Variable displacement motors
  
- c) **Acceleration /Deceleration referring to:**
  - (i) Cushioning devices
  - (ii) Proportional directional control valves
  - (iii) Pump and motor displacement controls
  - (iv) External cushioning devices (deceleration valves)
  
- d) **Force/Torque referring to:**
  - (i) Pressure reducing valves
  - (ii) Pressure relief valves
  - (iii) Pump compensators
  - (iv) Motor displacement controls

HSD4.8.2 Describe fixed and variable displacement pump control systems with respect to:

- a) Unloading systems
- b) Multiple pump combinations
- c) Accumulator applications
- d) Pressure compensation, single and multiple pressure controls
- e) Load sensing
- f) Torque limiting/constant power

HSD4.8.3 Prepare hydraulic circuitry using relevant ISO 1219-1 standard symbols to meet the prescribed functional specification.

HSD4.8.4 Compare the alternative circuit solutions with respect to power transmission efficiency and system cost.

**KNOWLEDGE BASED MODULE HSD4.9 - Component Selection**

## Reference to Manufacturers Technical Data

- HSD4.9.1 Outline the factors which affect the selection of the various types of pumps, to include:
- a) Gear (internal/external)
  - b) Vane (fixed and variable)
  - c) Piston (fixed and variable)  
(axial, bent axis and radial)
- HSD4.9.2 Outline the factors which affect the selection of the various types of motors, to include:
- a) Gear
  - b) Vane
  - c) Gerotor/orbit
  - d) Axial piston
  - e) Radial piston
  - f) Cam
- HSD4.9.3 Outline the factors which affect the selection of the various types of cylinders, to include:
- a) Single acting (displacement)
  - b) Double acting
  - c) Double rod
  - d) Telescopic
  - e) Cylinders incorporating integral position sensors
  - f) Internal cushioning
- HSD4.9.4 Outline the operating characteristics of flow control devices and state the criteria for sizing and selection relating to:
- a) Non-compensated flow control valve, e.g. throttles
  - b) Compensated flow control valves
  - c) Spool and rotary flow dividers
- HSD4.9.5 Outline the operating characteristics of direction control devices and state the criteria for sizing and selection relating to:
- a) Check valves
  - b) Pilot operated check valves
  - c) Pre-fill valves
  - d) Poppet and spool valves with reference to:
    - (i) AC/DC solenoid characteristics (response time, holding and inrush current)
    - (ii) Flow, pressure & power characteristic
    - (iii) Configurations – spring centred, offset, detent
    - (iv) Spool options and position monitoring
    - (v) Two stage valves (including interface modules, internal/external XY ports)
  - e) Slip in cartridge and screw in cartridge

- HSD4.9.6 Outline the operating characteristics of pressure control devices and state the criteria for sizing and selection relating to:
- Poppet and spool valve
  - Single stage and two stage units
- HSD4.9.7 Outline the criteria for selecting the following valve methods of control:
- Manual
  - Pilot
  - Solenoid
  - Solenoid pilot
  - Proportional
  - Servo
- HSD4.9.8 Explain the methods for controlling over-running loads using:
- Simple restrictor or proportional valves
  - Pressure compensated flow control valves
  - Pilot operated check valves
  - Counterbalance valves
- HSD4.9.9 State the hydraulic fluid classifications relating to ISO 6743.
- HSD4.9.10 Outline the characteristics of hydraulic fluids that affect their criteria for selection.
- HSD4.9.11 Describe the following types of oil coolers and outline their principle of operation:
- Air blast
  - Water coolers
- HSD4.9.12 Describe the difference in performance between the following types of filters:
- Depth
  - Electro-static
- HSD4.9.13 Explain the rating system used to determine filter performance to achieve a target cleanliness level.
- HSD4.9.14 Outline the factors that affect the selection of the following types of accumulator:
- Bladder, with and without backup bottles
  - Diaphragm
  - Piston
- HSD4.9.15 Describe the safety block arrangements used in conjunction with accumulators.
- HSD4.9.16 Outline the selection criteria and application of pipes, hoses and fittings (interconnection methods) with reference to current BFPA Guidelines.
- HSD4.9.17 Outline the design features to be considered in the design of reservoirs for mobile and industrial systems.

**KNOWLEDGE BASED MODULE HSD4.10 - Control System Design**

- HSD4.10.1 Explain the difference between open and closed loop control systems and outline the selection criteria relating to:
- Accuracy
  - Speed of response
  - Cost
- HSD4.10.2 Explain the meaning of the following terms and calculate as required:
- System hydraulic stiffness
  - Hydraulic natural Frequency
  - Valve response
  - Valve pressure/flow characteristics
  - System loop gain
- HSD4.10.3 Describe, the factors to be considered for the design of closed loop control systems
- Load characteristics
  - Actuator characteristics
  - Sensor characteristics
  - Leakage
  - Fluid viscosity
- HSD4.10.4 Determine control valve size to meet the performance specification.
- HSD4.10.5 Determine maximum loop gain for stable operation of the closed loop system, considering the following:
- Amplifier gain
  - Control valve gain
  - Actuator gain
  - Feedback gain
- HSD4.10.6 Explain the process for estimating steady state errors on a closed loop control system.
- HSD4.10.7 Explain the effect of proportional, derivative and integral control terms relating to position, velocity and pressure control.

**KNOWLEDGE BASED MODULE HSD4.11 – System Performance Evaluation**

- HSD4.11.1 Verify that the supply flow matches the actuator demand under all working conditions.
- HSD4.11.2 Verify that available pressure at the actuator meets the specification under all working conditions.
- HSD4.11.3 Verify that motors have sufficient capacity for the given torques and sufficient shaft strength and bearing capacity for driving the load.
- HSD4.11.4 Verify that cylinders have sufficient strength for the required stroke length. Ensure that cylinders can accommodate side forces, where these occur.
- HSD4.11.5 Determine the system pressure losses.
- HSD4.11.6 Determine the pressures that will arise in all parts of a system and ensure that they do not exceed the component manufacturers' specification under all operating conditions.
- HSD4.11.7 Determine the settings of all adjustable components.
- HSD4.11.8 Calculate the required accumulator capacity and pre-charge pressure for the specified operating pressure range and flow output during a duty cycle.
- HSD4.11.9 Determine the power losses in the system that will arise under all working conditions.
- HSD4.11.10 Determine the heat generated and the maximum oil temperature created under the worst operating conditions.
- HSD4.11.11 Determine a suitable size of oil cooler to control the oil temperature within the specified temperature range.
- HSD4.11.12 Determine that the contamination control system meets the required target cleanliness specification. (Reference BFPA/P5)

**KNOWLEDGE BASED MODULE HSD4.12 - Systems Management/Configuration**

- HSD4.12.1 Outline the following methods used for evaluating possible system failures:
- a) Fault Tree Analysis
  - b) Failure Mode & Effect Analysis (FMEA)
- HSD4.12.2 Identify the system parameters that can be used for condition monitoring.
- HSD4.12.3 Identify suitable positions within a system for test and sampling points.
- HSD4.12.4 List the types of sensor that are suitable for condition monitoring purposes.
- HSD4.12.5 Develop a “step by step” procedure to be followed when carrying out:
- a) installation
  - b) commissioning
  - c) condition monitoring
  - d) maintenance
  - e) fault finding

**(Risk assessment and safe working practices to be clearly identified)**

## **APPENDIX**

### **Suggested Practical Laboratory Investigations:**

- Throttle valves vs pressure compensated flow controls
- On-off valves vs proportional control for shock reduction
- Cylinder characteristics under varying conditions:
  - (i) Friction
  - (ii) Speed control (meter-in and meter-out)
  - (iii) Intensification
  - (iv) Load holding and motion control using pilot operated check valves and counterbalance
- Load sensing vs pressure compensation
- Pump performance (Q/P relation slip and case drain flow under varying load conditions)
- Comparison of pressure-flow characteristics for proportional throttle valve:
  - (a) Non-feedback
  - (b) Feed-back
  - (c) Feed-back plus hydrostat

### **Recommended Reference Literature**

- Principles of Hydraulic System Design by Prof: P Chapple (via BFPA)
- Power Hydraulics by Pinches and Ashby (Sheffield Hallam University Press)
- Principles of Proportional Valves (Eaton Corporation)
- Closed Loop Electro-Hydraulic Systems Manual (Eaton Corporation)
- Planning and of Design Hydraulic Power System Book Vol 3 (Rexroth UK)
- Control of Fluid Power (Analysis and Design) by D McCloy & HR Martin
- Hydraulic Hand Book (9<sup>th</sup> Edition)
- BFPA Guidelines (List available on request)