Technical requirement for development, supply of CRDI FIS with EMS to the given specification & requirements including Engineering Support

1 INTRODUCTION

BEML Limited was established in May 1964 as a Public Sector Undertaking and plays a pivotal role serving India's core sectors such as Defence, Rail, Power, Mining and Infrastructure. The manufacturing units located at Bangalore, Kolar Gold Fields (KGF), Mysore and Palakkad along with all India Sales & Service network and backed up by a strong R&D base. For more details please visit www.bemlindia.in.

2 PROJECT BACKGROUND

BEML, in association with CVRDE, has taken on the development of a 1500Hp, 12V, 25Ltr capacity diesel engine for use within an Armoured Fighting Vehicle (AFV), to meet Indian Military requirements.

BEML has hired RICARDO for design & development activities, supplier selection and technical support throughout the duration of the Project. BEML shall manufacture & test the engine and supply to CVRDE for field trials. BEML, RICARDO & CVRDE shall work jointly on this project.

A project period of 5 years is envisaged from design phase to serial production stage. An Initial manufacture run of 20 engines are planned to prove out (test bed and field trials) at BEML. Serial production will begin (75 No/Annum envisaged) after a successful completion of these trials.

The engine design concept refinement phase is completed, and key engine specifications are finalised. The specification defined within this RfQ should be considered the master document for the technical requirements.

BEML will look forward to working with the CRDI (Common Rail Direct Injection) fuel system suppliers for this prestigious project of national importance. Interested suppliers are requested to share their robust CRDI (Common Rail Direct Injection) fuel system details suitable to this project and supply the CRDI complete system to Engine Division, BEML Ltd., Mysore. The scope of supply and scope of work is enclosed with this RfQ.

Once the supplier is nominated to this project through tender, they have to jointly work with the RICARDO team to finalise the design and supply the CRDI (Common Rail Direct Injection) FIS (Fuel Injection System) including EMS (Engine Management System).

The supplier is expected to engineering support to interface all the electrical & electronics components on Engine and Vehicle including all necessary trials on test bed and Vehicle.

3 PROJECT APPROACH & TIMING

As soon the Purchase Order is placed by BEML, the project timeline will start immediately. Hence BEML expected Off-The-Shelf products from the suppliers. However any modifications are required for this project supplier ready to make necessary changes on their proposed components since the Engine design was frozen.

4 ENGINE SPECIFICATION:

Engine Type	:	12 Cylinder, 4-stroke, V-90 configuration, Turbocharged, Intercooled, DI, liquid cooled Diesel Engine
Swept Volume	:	25.13 Lit (Bore: 138 mm & Stroke: 140 mm))
Rated Power a) Performance at 55^0 C ambient temperature at sea level b) Performance at 1000m altitude c) Performance at 5000m altitude	: : : :	1103 kW as per ISO 1585 (w/o fan) No power reduction allowed No power reduction allowed Engine should be able to operate upto 5000m altitude safely. Minimum power reduction is permissible at this altitude.
Torque backup (min)	:	18% at 60%-65% of rated engine speed
Maximum allowed rated speed	:	2800 rpm
Power at 50% rated speed (min)	:	610 kW
Power at idling speed (min)	:	140 kW
SFC at peak torque speed	:	210 g/kW.hr (max)
Continuous over speed	:	110% of rated speed
Instantaneous over speed	:	125% of rated speed
Engine Dimensions	:	Engine with all its constituents will have the following dimensions: Length: 1570 mm Width: 1025 mm Height: 1115 mm
Engine Life (for Qualification)	:	400 hrs as per CVRDE Driving Cycle
Engine Life (before overhauling)	:	1200 hrs
Fuel	:	Diesel DHPP-A and its variants
Oil Sump	:	Dry sump
Permissible inclination of Engine	:	35° in any direction. Engine should be able to stop for any duration and start under these inclinations
Dry weight	:	i. Max. Permitted : 2200 kg ii. Desired weight limit : 2100 kg
Startability	:	Engine should be able to start at -30° C with starting aid.
Firing Order	:	1-12-5-8-3-10-6-7-2-11-4-9

Max torque	:	4780 Nm at 1560 rpm
Idling speed (Minimum)	:	800 +/- 200 rpm
Idling speed (Maximum)	:	2860 rpm
Thermodynamic Peak Firing Pressure (Simulated)	:	180 bar
Compression Ratio	:	15.5 : 1

1D THERMODYNAMIC SIMULATION: (DRAFT)

SL NO	Engine Speed	Power	Torque	SFC	BMEP
	rpm	kW	Nm	g/kWh	bar
01	2600	1103.00	4051.11	222.24	19.56
02	2400	1093.29	4350.07	212.36	21.00
03	2200	1046.24	4541.29	204.94	21.93
04	2000	981.16	4684.69	199.72	22.62
05	1700	850.95	4780.00	192.64	23.08
06	1560	780.92	4780.30	189.00	23.08
07	1300	610.00	4480.82	192.77	21.64
08	1000	300.00	2864.79	197.40	13.83
09	800	140.00	1671.13	206.58	8.07

5 PROJECT KEY STAGES:

- FIS &EMS Supplier Kick Off
- Phase 1: Gen 1 Design
    - Application engineering of the EMS to fulfil the technical requirements of the engine (functionality, diagnostics, interfacing, etc)
    - Support for HiL testing of EMS
    - FIS System specification and design freeze
    - Supply FIS and EMS
    - Gen 1 Prototype Engine Build
- Phase 2: Gen 1 Development
    - Support engine first fire
    - Gen 1 Prototype Engine Testing
    - Hardware screening including nozzles screening
    - Support for Engine durability testing
- Phase 3: Gen 2 Development
    - Design update & component development
    - Supply of updated FIS and EMS

    - Calibration update
    - Support for Engine durability testing
- Phase 4: Powerpack Testing
    - ECU and TCU Integration & Vehicle Testing.

6 PROJECT RESPONSIBILITIES – PROPOSED RASIC TABLE (DRAFT)

Item	Supplier	BEML	Ricardo	CVRDE	Other
Specification of the overall engine E/E system to meet application requirements	S	A	R		
Management of E/E system suppliers to ensure E/E system deliverables achieved	S	A	R		
FIS (CR system)					
Requirements & Design Validation					
System hardware requirements	S	A	R		
System functionality requirements	S	A	R		
Definition of FIS system proposal	R	I	A		
FIS system functional validation on engine	S	A	R		
FIS system durability validation on engine	S	R	S		
Design Validation (DV) of proposed FIS components to meet project requirements	R	I	A		
DV review and approval	R	A	S / C		
Performance/Simulation/Testing Assessment					
Definition of nozzle library for simulation assessment	I	I	R		
Provision of proposed nozzle library	R	I	I		
Provision of FIS measured data to assist performance/simulation evaluation	R	I	A		
Simulation assessment of proposed nozzle library	S	I	R		
Recommendation of FIS specifications to progress to testing phase	S	I	R		
Provision of HW to meet requirements and to support testing phase	R	I	I		
Hardware testing (including nozzle screening) and performance assessment	S	A	R		
Approval of final HW selection	I	R	S / C		
Design					
Provision of installation requirements	R	I	I		
Definition of packaging space/requirements	C / I	I	R		
Provision of FIS related CAD models	R	I	I		
Assessment of FIS related CAD models & Engineering on engine	C / I	I	R		
Design of HP pipes (Note: HP pipe supplier to Approve)	S	I	R		S
Injector clamp design	S	I	R		

EMS					
Specification of System Requirements					
System hardware requirements	**S**	**A**	**R**		
System functionality requirements	**S**	**A**	**R**		
Hardware specification to meet requirements	**R**	**I**	**A**		
Software Functionality					
Provision of description of existing EMS software	**R**	**I**	**I**		
Supply of all software integrated into EMS (ASW / BSW)	**R**	**I**	**I**		
Review of existing software functions; identification of modification requirements	**S**	**A**	**R**		
Specification of new software functions	**S**	**A**	**R**		
Implementation of new software functions	**R**		**A**		
Input / Outputs					
Sensor selection	**S**	**A**	**R**		
Actuator selection (except FIS)		**A**	**R**		
Confirmation of sensor & actuator electrical compatibility with EMS	**R / A**	**I**	**S**		
EMS External I/O definition (discrete I/O, CAN messages, etc, including integration with Transmission & Vehicle)	**S**	**A**	**R**	**S**	
EMS pin-out definition, connector specifications	**R**	**I**	**I**		
Harness pin-to-pin definition	**S**	**A**	**R**	**S**	
Harness build					**R**
Diagnostics					
Provision of description of existing EMS fault tolerance / fault handling system	**R**	**I**	**I**		
Review of existing diagnostics & fault manager; identification of modification requirements	**S**	**A**	**R**		
Specification of diagnostic modifications		**A**	**R**		
Implementation of diagnostic modifications.	**R**		**A**		
Specification of fault reactions for diagnostics as per label split agreement	**S**	**A**	**R**		
Calibration and configuration of diagnostic as per label split agreement	**S**	**I**	**R**		
Pre-calibration and configuration of diagnostic manager	**R**	**I**	**S**		
Provision of comms protocol specification for ECU fault code interrogation (to enable fault code interrogation by HMI)	**R**	**I**	**I**		
Support for HiL Testing					
Testing of EMS on HiL test facility (test of control & diagnostics)	**R**	**I**	**A**		
Specification of HiL system for EMS integration testing (to test integration of EMS and HMI unit). Note: Supplier to provide details relevant to operating EMS on HiL facility	**S**	**A**	**R**		

Provision of EMS calibration for HiL integration testing	R	I	A		
Engine Testing					
Calibration of FIS control	R	I	A		
Supply of safe calibration for engine testing	R	I	A		
System commissioning on engine, to engine first fire	S	I	R		
Full SW strategy guide and HW operation manual	R	I	A		
Provision of open ECU with calibration access	R	I	A		
Provision of software flashing tool	R	I	A		
Supply of calibration / Diagnostic tool	R	I	A		
Calibration to performance targets		I	R		
Calibration modifications to diagnostics		I	R		
Calibration build & release	R	I	S / A		
Specification of SW changes resulting from engine testing		A	R		
Implementation of SW changes resulting from engine testing	R	I	A		
Functional validation testing on Gen 1 engines	S	A	R		
Durability validation testing on Gen 1 engines	S	R	S		
Functional & durability validation testing Gen 2 engines	S	R	S		
EMS Robustness Testing					
Environmental & robustness testing (as per Technical Specification)	R	A	S		
EMI/EMC testing (as per Technical Specification)	R	A	S		
Vehicle Testing					
Validation of EMS integration with TCU and vehicle systems, and EMS vehicle calibration update	S	S	R		
Validation testing of powerpack and in vehicle	S	S	S	R	
Support For Display unit integration	S	I	R		
Training	R	I	I		

7 MAIN FEATURES OF FUEL INJECTION SYSTEM (CRDI):

1. High Pressure Injection system
2. Variation of Injection timing as a function of engine speed & load for optimum performance
3. Variation of Injection pressure as a function of engine speed & load for optimum performance
4. Multiple Injection / Split Injection system (Min 5) with Injection quantity and injection timing optimisation as a function of engine speed & load for optimum performance
5. Charge air pressure & temperature compensation
6. Coolant temperature based fuelling control (derating mechanism) for limiting coolant temperature
7. Electronically (ECU) controlled Waste Gate and related map
8. Emergency shut-down provisions for Low lubrication oil pressure, No coolant flow, Low coolant level
9. Engine has to be electronically controlled
10. Ethernet and MILCAN / SAE J-1939 interfaces are required for electronic controller
11. The engine design shall be able to accommodate both Mechanical fuel injection system (with electronic controller) and Common Rail Direct Injection system with the same drive train. (Preferred CRDI pump drive speed is half of the engine speed)
12. The engine has to be designed and optimized for Common Rail Direct Injection system.
13. Selective engine cylinder firing option may be considered.
14. Fuel injection system and its components shall be robust and work satisfactorily in all operating conditions (-30 ^{o}C to +200 ^{o}C inside engine compartment)
15. Max redundancy should be provided in order to ensure that the engine shall keep running in case of various failures in the fuel injection system / electrical systems.
16. The Engine Control Unit should have the following features
    a. POST(Power On Self Test) & BITE(Built In Test Equipment) facility should be provided
    b. Downloading access for firmware/software
    c. Cater for Logging of diagnostic data with Post analysis software for analyzing the logged data.
    d. Cater for additional digital I/O and analog I/O for interfacing with other signals of Power pack.

e. Fault tolerant system architecture should be used. (in the event of any component/device/subsystem failure, the system continues its intended operation, possibly at reduced level rather than failing completely)

f. Engine should have auto shutdown under these conditions

   1. Low engine oil pressure.

   2. Coolant flow failure.

   3. Coolant loss

   Engine ECU should indicate Malfunction warning to TCU and VCU in case of engine failure/auto shutdown.

g. Make Diagnostics data available in a gateway for interfacing with the vehicle.

h. All electrical & electronic systems in the engine including the ECU, Injectors, sensors & actuators to comply with environmental specifications (Enclosed) and EMI /EMC compliance as per MIL STD 461 G.

i. IP67 protection,

j. ECU & TCU (Transmission Control Unit) integration

k. ECU & VCU (Vehicle parameters like START, STOP, Power De-rating, Emergency, Fording Signal etc.,) integration

l. All electrical & Electronics components should meet CVRDE's Environmental (details are attached) & EMI / EMS standards as per MIL STD 461 G

m. Refinement of engine control strategies, ECU calibration & final setting of FIS in vehicle and performance verification with vehicle conditions.

8 SCOPE OF SUPPLY

A. The FIS and EMS system kit (**123 400 0172**) to be developed and delivered by the Supplier shall consist of:
   - Rail Assembly
   - Injector Assembly with side feed connector (Quill pipe) type is mandatory
   - High-Pressure (HP) Pump
   - High Pressure pipe set (Optional)
   - Engine Management System (as an integrated hardware and software solution)
   - Sensor Set (Optional)
   - Installation and mounting accessories (if any).

B. EMS software flashing & Calibration (Including Diagnostic) tool – 123 809 0236 - consisting of the hardware and software required to flash the updated software & Calibration of ECU parameters.

8.1 Engineering

Development of FIS and EMS system to fulfil the technical requirements defined in section “Technical Specification”, including technical support to engineering of the FIS and EMS into the engine according to the responsibilities defined in “Project Responsibilities – Draft RASIC Table”.

8.2 Physical Scope of Supply

8.2.1. The provision of the FIS and EMS system shall include the following parts for V-12 Engine specification / configuration as given in section 4:

SI No.	Overall Specifications	Ref Dwg Number	Qty/ Engine
1	**CRDI FIS Kit** **(Consist of 1a to 1e)**	123 400 0172	**1 Kit**
1a	CRDI RAIL ASSY	123 400 0197	**01 set**
1b	CRDI INJECTOR ASSY (Incl. Side feed connector)	123 400 0204	**12 set**
1c	CRDI HP PUMP	123 400 0189	**01 set**
1d	Engine Management System (EMS)	123 809 0228	**01 set**
1e	EMS Calibration & diagnostic tool (software+ hardware)	123 809 0236	1 No
1f	High Pressure pipe set (optional)	123 400 0212	**1 set**
1g	Sensor Set (Optional)	123 809 0244	**1 set**
1g.1	Oil Level Switch	123 629 0189	**1 set**
1g.2	Level Sensor	123 629 0123	**2 set**
1g.3	Crankshaft Position Sensor	123 629 0026	**2 set**
1g.4	Camshaft Position Sensor	123 629 0034	**2 set**
1g.5	Temp. Sensor	123 629 0042	**6 set**
1g.6	Sensor (Pressure & Clogging)	123 629 0107	**2 set**
1g.7	Sensor (Pressure & Clogging)	123 629 0075	**4 set**
1g.8	Accelerator Pedal Sensor	123 629 0115	**1 set**
1g.9	Oil Pressure Switch	123 629 0067	**2 set**
1g.10	Fuel Pressure Switch (Low Pressure)	123 629 0148	**1 set**

Note: CRDI FIS Kit to be included with necessary installation and mounting accessories.

The quantity of component/ Engine to be defined by the bidder that required for the Gen 1 & Gen 2 prototype engine testing.

8.2.2. Two No's of EMS software Calibration & Diagnostic tool, including both hardware and software (required to flash the updated software & Calibration of ECU parameters). Please refer the drawing to part number – **123 809 0236.**

8.2.3. Critical CRDI FIS system spares & consumables recommended by supplier to carry out engine validation

8.3 Testing & Validation

8.3.1 Supplier to perform the following validation testing:

- FIS rig test to verify durability of CRDI HP (High Pressure) Pump & Injector
    - Supplier is responsible for defining the validation plan to ensure system durability and performance in the engine application
- Hydraulic simulations of CRDI FIS system components

8.3.2 Supplier to test electrical components for compliance to the following, and provide compliance evidence from testing to Ricardo & BEML:

- MIL-STD-461G (EMC/EMI)
- Environmental and Robustness Requirements, as defined in "Technical Specification", section **9.2.23** "ECU Hardware Robustness"

8.3.3 Supplier to support testing and validation of the engine by:

- Preparation of safe calibration of EMS, commissioning of EMS on the engine, support to engine first fire
- Provision of calibration builds and release of software updates to support testing phase

8.4 Documentation

Supplier to provide the following documentation as part of the scope of supply:

8.4.1 FIS

- Technical specification of all FIS system components
- Report including the hydraulic simulation results of CRDI HP pump and injector
- Report including the end of line (EOL) quantity measurement results and tolerance criteria
- Operation and maintenance manual and service & trouble shooting manuals of FIS system related components
- GA (General Assembly) drawing both 2D and 3D of complete system, its components and its specification
- Acceptance Test Procedure (ATP) and Acceptance Test Criteria (ATC) of the supplied parts
- Performance and durability test certificates of supplied parts
- Installation manual of all FIS system related components
- Report of Design Validation Plan (DVP) tests carried out additionally (if any)
- Details of Warranty Practices and Services in After Sales, Number of Years for which Spares and Service Support offered to Customers to be provided.

8.4.2 EMS / ECU

- ECU hardware specification
- ECU connector specifications
- ECU pin-out specifications
- ECU component drawings, with dimensions and installation requirements
- ECU software functional description, including: control functionality, diagnostics, fault reactions and fault manager
- ECU calibration guidelines
- ECU interface specifications (hardwire and communication bus interfaces, and communication protocol for fault code interrogation)
- ECU calibration tool requirements
- ECU software flashing tool
- Release notes for each Software and Calibration build & release
- EMS sensor requirements
- EMS HiL testing report
- EMS engine test bed test report
- Certificates of compliance and test reports of EMS to the electrical, EMC/EMI and environmental and robustness standards specified in the Technical Specification
- Details of Warranty Practices and Services in After Sales, Number of Years for which Spares and Service Support offered to Customers to be provided.

8.5 NOTE:

1. Any parts required to prove out standards & development are part of supplier scope.
2. Engine will be developed in 2 generations namely, Gen-1 (7 no's) & Gen-2 (15 no's). The total number of engines for both the generation is 22kits. For proto prove out, 5 sets to be considered.
3. All the test reports shall be provided along with the parts supply.
4. All parts are supplied with proper closing caps.
5. All parts shall be supplied in good seaworthy packing condition.
6. The given drawing is a preliminary drawing and final drawings to be submitted by supplier for approval which will be vetted by m/s Ricardo, UK.

9 PROPOSED TECHNICAL SPECIFICATION

9.1 Fuel Injection System (FIS) Specification

The FIS system shall meet the technical specification summarised in the table below.

Nominal FIS System Specification			
Nozzle flow rate [cc/min]	Number of holes [#]	Estimated hole size [mm]	Cone angle [°]
2700	8	0.229	144
Lower / Upper FIS System Specification			
Nozzle flow rate [cc/min]	Number of holes [#]	Estimated hole size [mm]	Cone angle [°]
2430 / 2970	7 / 9	0.205 / 0.256	140 - 150

Depending on the results achieved during the engine testing phase, alternative nozzle specifications may be requested with 3 options potentially required. The detailed changes to the nozzle specification would be confirmed at the time, however it is anticipated these may include modifications to the nozzle flow rate, cone angle or hole size.

In addition, the FIS system shall meet the following additional technical requirements:

- Maximum rail pressure capability of 2200bar
- Capable of supporting multiple injections (minimum of 3 to allow for usage of pilot injections, if deemed necessary during the testing/calibration phase) with Injection quantity and injection timing optimisation as a function of engine speed and load for optimum performance
- Fuel injection system related components shall be robust and work satisfactorily in all operating conditions (-40°C to +100°C inside engine compartment)
- The FIS and EMS system will be powered by an alternator-battery electrical supply, and the FIS and EMS system shall be compliant with MIL-STD-1275E. This standard defines protection requirements for overvoltage, reverse polarity, transients, etc.
- The FIS and EMS system shall operate on an electrical supply voltage range of 9-36V DC (which is a larger voltage range than defined in MIL-STD-1275E) .
- The FIS and EMS system shall be compatible with the EMI & EMC requirements defined in MIL-STD-461G.

9.2 Engine Management System Specification

The requirements of the EMS that are to be fulfilled by the Supplier are defined in this section:

9.2.1 Engine Start Management

This function will coordinate ECU start-up checks when the ECU is powered on, followed by firing once the engine speed is above a predetermined engine speed threshold. The IP will manage the engine cranking, covering the electric starter motor, air starter, and tow start cranking methods. (ECU to co-ordinate of firing of engine during cranking, when start requests from Input Panel (IP)).

The TCU will be responsible for providing a "Neutral Start Condition" hardwire signal to communicate when it is safe to fire the engine.

The operator will use the Input Panel (IP) – the operators HMI – to set the "Start Interlock Bypass Switch" hardwire to ON to command the ECU to override the TCU neutral start signal, allowing it to start the engine regardless of the Neutral Start Condition status.

The ECU will be able to start and run the engine with either the crank position sensor or cam position sensor failed.

9.2.2 Engine Start Interface

The operator will use a 3-position rotary (0-I-II) master key switch to control power to the electrical systems, according to the following positions:

Position	**Functionality**	
Position 0	All systems to be powered off in the vehicle.	Main relay switched OFF. The main relay controls the power of the complete vehicle electrical system.
Position 1	Standby position: IP to be powered ON, and will start-up.	Main relay to be powered ON, supplying power to systems in vehicle.
Position 2	Drive position: ECU to be powered ON, fuel pumps to be switched ON.	Drive relay should be switched on feeding power to ECU and TCU and drive electronics. Power to the Fuel Fired Coolant Heater unit to be cut.

The operator will then use several individual switches, which will be hardwired to the ECU, to indicate their intended start method, from the following options:

Switch	Details
Pre-Glow Start	Normal start procedure The preglow push button has two momentary positions: **Preglow** and **Start** 1) The pre-glow position allows to operator to manually request the fuel fired intake air heaters to be used to support cold starts 2) Following a start request from the IP, the ECU will coordinate firing of the engine when it reaches a nominal speed.
Emergency Start	When this switch is ON, the ECU will be bypassed and direct 24V will be applied to starter motor. The ECU will coordinate firing of the engine when it reaches a nominal speed.
Tow Start	Tow start is an alternative cranking method for when minimal voltage is available from the vehicle. The ECU will coordinate firing of the engine when it reaches a nominal speed.

Air Start	Air start is an alternative cranking method to be coordinated by the IP when the electrical starter motor is not available. The ECU will coordinate firing of the engine when it reaches a nominal speed.

9.2.3 Engine Cold Start (Optional)

The engine must be able to start at -40°C. In order to support this requirement, it will be necessary to pre-heat the fuel, the coolant circuit and the intake air. The EMS shall command the Fuel Fired Air Heaters when the pre-glow momentary push button is activated.

The engine start function commanded by the IP shall coordinate the other related functions using the following components:

- Fuel fired coolant heater(s) (FFH) to heat coolant in the high-temperature coolant circuit
- LP heated fuel filter and trace line heater to heat the fuel to be delivered to the engine

The ECU will need to support pilot injection of fuel to facilitate a cold start – one or two pilot injections may be required.

9.2.4 Engine Stop Management

This function will coordinate stopping the engine, which can be demanded by:

1) Engine stop button
2) MKS switch from II to I or 0
3) Automatic shutdown for engine protection (note it will be possible to override the automatic shutdown in certain scenarios)

The engine can be stopped by a fourth route: the operator hitting the emergency stop switch – this will cut electrical power to the ECU, forcing an engine shutdown.

If the diagnostics function commands the engine to shutdown (i.e. option 3 above), then the ECU will set the “Engine Auto Shutdown” hardwire to ON and shut down the engine.

If the engine is stopped at any point, for any reason, then the ECU will set the “Engine shutdown indication” hardwire to ON.

9.2.5 Engine Load Control

The ECU will require a torque structure to manage the multiple engine torque requirements on the engine, including operator demand, transmission torque requirements, ancillary loads and any torque limits. The torque structure will output the required engine indicated torque, and pass this to the fuelling and airpath controllers.

The torque will need to be limited to within the physical limits of the engine and associated systems, and the rate of change of torque may also need to be limited if any component requires this for protection.

The transmission will need to limit engine torque to complete gearshifts. This should be commanded by the TCU to the ECU via CAN, according to MiLCAN / J1939 protocol.

The engine torque will need to be limited for engine protection in the presence of certain faults (see diagnostics function description).

If the engine performance is limited for any reason, the ECU will set the “Engine Override” hardwire signal to true.

An idle speed controller should be implemented to maintain idle speed.

A speed controller should be implemented to allow the engine to be operated in speed control mode.

An engine speed limit should be implemented to avoid engine over speed, by limiting fuelling as necessary.

9.2.6 Fuelling Control

The ECU will inject fuel as required to start the engine.

The ECU will inject fuel according to the required number of injections, injection timing, and injection quantity to achieve the required engine torque demanded by the “Engine Load Control” function, with optimised combustion for the current operating point.

The ECU will limit fuelling to within a calibrated smoke limit, using the estimated air charge.

The ECU will support main and pilot injections if required to achieve robust combustion across all engine operating conditions.

The ECU will compensate fuelling quantity and timing, as required to protect the engine and ensure robust combustion across all engine operating conditions.

The ECU will target a fuel pressure in the high-pressure fuel rail(s) according to the demands of the injectors and the engine operating point. The ECU will control the HP pump metering valve and fuel rail pressure relief valves to achieve the target rail pressure.

If the fuel temperature rises beyond safe operating conditions, the ECU will de-rate the high-pressure fuel system.

On emergency shutdown, the FIS system will deplete any high pressure and prevent any fuel being injected into the engine.

Where faults are detected in the FIS, the ECU will de-activate failed components (e.g. injectors) to protect the engine, but will continue de-rated operation where possible.

9.2.7 Air-path Control

The ECU will estimate the air charge into the cylinders based upon the current engine speed and the TMAP measurement. The air charge estimation will then be used to calculate the maximum fuelling such that the smoke generated by combustion remains lower than the engine smoke limits.

The ECU will calculate the target boost pressure based on the engine operating condition and control the two turbocharger wastegates to achieve the target pressure via electronically actuated Pressure Regulating Valves (EPRVs).

The ECU boost controller will need to incorporate turbocharger overspeed protection, with use of measured ambient pressure to ensure overspeed protection at altitude.

9.2.8 Emissions Control

The only emissions limit is on smoke. Therefore, there will be no emissions after treatment system present. The smoke limits are as follow:

Condition	Limit
Nominal full load	0.6 FSN
Max. Steady State	1.5 FSN
Max. Transient	4.0 FSN

The ECU should incorporate a smoke map which will respect these targets by limiting fuel injections to a specific lambda, based upon the calculated AFR. This map will be calibrated during engine development, with no active monitoring possible during normal engine use.

9.2.9 System Temperature Control

The cooling system will be used to manage the temperature of the base engine, the WCAC, the bulk fuel, bulk engine oil and bulk transmission oil using mechanically driven coolant pumps.

The cooling system will comprise of two circuits. One low-temperature circuit serving the fuel, oil and air coolers as well as turbochargers, and a second high-temperature circuit serving the base engine.**ECU monitoring of both coolant circuits shall be active but fault reactions are only required for the high-temperature circuit.**

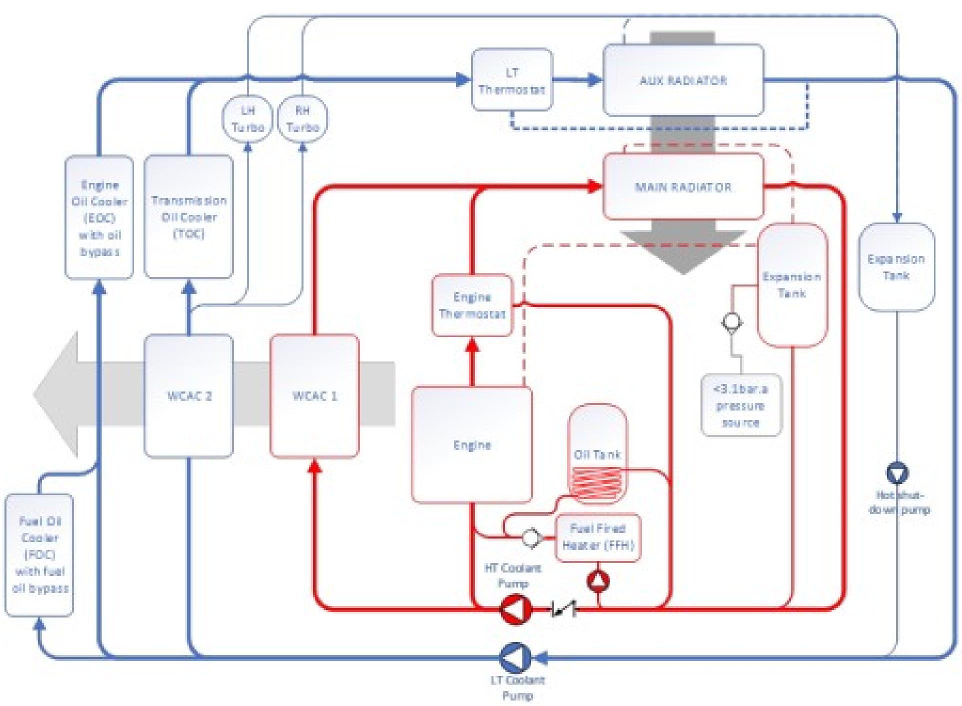


Figure 1: High and Low Temperature Circuits BE1500 (*Proposed*)

A separate EMS controlled coolant pump shall be used to maintain adequate cooling of the turbochargers in the event of a hot shut down by continuing to run after the engine has stopped.

The duration of this after-run functionally shall be determined during the development phase and should be configurable.

The TCU will control the radiator fans to reduce the temperature of both circuits when requested by the ECU. If communication is lost between TCU and ECU, the TCU should default to setting the radiator fans ON.

9.2.10 Smoke Generator (Optional)

A smoke generation kit will be installed in the engine. This will generate smoke by injecting fuel through a solenoid-controlled injector into the exhaust stream, downstream of the turbine. This system shall be managed entirely by the IP.

9.2.11 I/O & Networking

The ECU will communicate to other components within the vehicle and engine system through a combination of CAN and hard-wires. The operator will interact with an Input Panel (IP) which contains several switches triggering responses from the ECU. The IP will also display live information from the ECU as well as logging diagnostic information and engine/vehicle data within it's hard drive.

The ECU will support CAN networking to MilCAN/SAE J1939 standards. This will be used for communication between the ECU, TCU, IP and Vehicle Gateway.

For an overview of all components to interface with the ECU, see section "System Schematic".

Development versions of the ECU will provide an engineering interface into the ECU memory (for example, XCP), to facilitate engine controller parameter calibration. This chosen interface protocol needs to support sufficient logging and calibration access as necessary for the engine calibration activity. This is not required on production versions, and interfacing to the ECU for in-service diagnostics interrogation, etc will be via CAN.

9.2.12 I/O & Networking Hardwire Interface

The ECU will receive the following signals from individual hard-wired interfaces from the IP:

- Pre-Glow (intake air heating) Start
- Emergency Start
- Air Start (same as 'Emergency Start')
- Engine Stop
- Fording Switch (same as 'Battle Mode')
- Override / Battle Mode (to override any engine performance limitations)
- Tow Start (same as 'Emergency Start')
- Spare Hardwire In x 6

The ECU will send the following signals as individual hard-wired warning lamps/ interfaces to the IP:

- Engine Auto Shutdown (this signal should also be sent to the TCU by branching from this hardwire)
- Central Warning Indication
- Engine Shutdown Indication
- High Coolant Temperature
- Low Oil Pressure

- Accelerator Pedal Signal Failure
- Coolant Pressure Warning
- Coolant Level Warning
- Engine Override
- Spare Hardwire Out x 6

The ECU will receive the following signal as a hard-wired interface from the TCU:

- Neutral Start Condition

9.2.13 Diagnostic Monitoring, Fault Handling and Fault Tolerance

The ECU diagnostic system will perform internal tests and monitoring, during both startup and operation, to check for correction operation of the ECU itself.

(Eg-1: ECU will monitor Engine Oil, Coolant & Fuel level and give appropriate warning to the IP (Instrument Panel).

Eg-2: ECU will monitor Engine Oil, Air & Fuel filter clogging level and give appropriate warning to the IP.)

The ECU diagnostic system will monitor sensor and actuator health and provide appropriate warnings in case of failure of sensors or actuators.

The ECU diagnostic system will monitor all ECU inputs and outputs for electrical circuit continuity.

The ECU diagnostic system will include monitors to check the plausibility of the input and output signals.

The ECU diagnostic system will need to monitor components and systems continuously where possible. Any non-continuous diagnostics should be completed regularly, and their completion status will be recorded by the ECU.

The ECU diagnostic system will monitor communication interfaces with other systems.

The ECU diagnostic system will need to store a fault code for any faults that are detected.

The ECU diagnostic system will trigger appropriate fault reactions once a fault is detected in order to protect the component, the engine and other connected systems, and to provide continued operation in the presence of faults (“fault tolerance”). The appropriate fault reaction will be dependent on the specific fault, but will include operational restrictions (e.g. torque limitations (Based on Altitude, Coolant Temperature etc.,), bank/cylinder deactivation), and the use of backup measurement or estimated values for control. Where torque limits are applied, the ECU will inform the operator through the IP.

The operator may set the “Override” switch on the Input Panel to override any engine power limitations. If the “Override” hardwire is ON, the ECU will disregard diagnostic limp home command and remove any engine power limitations.

The ECU diagnostic system will provide support for the retrieving of engine diagnostic fault codes and information logged in the ECU, via the IP.

The fault handling system will log and store all faults detected in the ECU. Each fault will be given a unique code and an associated message that appropriately describes the specific fault. The fault handling system will store key operating information from the engine and external conditions when the fault occurred.

The fault handling system will allow the faults to be communicated outside of the ECU, to support illumination of warning lights to the operator.

The fault handling system will allow faults to 'clear' themselves when the fault is no longer present and other conditions are met that give confidence that the fault no longer exists.

The fault handling system will be configurable in calibration to allow the individual faultcodes / fault descriptions / fault reactions to be specified.

The fault handling system will set the "Central Warning Indication" hardwire to true when a confirmed fault is flagged.

9.2.14 Application Specific Fault Handling

If the diagnostic system identifies that any of the following faults have occurred, then it will set the corresponding hardwire signal to the Input Panel to ON:

- High Coolant Temperature
- Low Oil Pressure
- Accelerator Pedal Signal Failure
- Coolant Pressure Warning
- Coolant Level Warning

The ECU will shut down the engine if faults are detected which risk damage to the engine, and should include detection of any of the following faults:

- Low Engine Oil Pressure
- Low Coolant Pressure
- Coolant Loss

9.2.15 Diagnostic Control Interface

The ECU will communicate with the Input Panel as the main diagnostic interface in production versions of the engine. During development, diagnostics will be developed, calibrated and validated.

The EMS will include a range of sensors available for diagnostics:

- Fuel filter clogging sensor
- Fuel pressure sensor (Low pressure fuel)
- Fuel pressure sensor/s (high pressure fuel)
- Fuel temperature sensor/s (high pressure fuel)
- Water-in-fuel sensor
- Coolant pressure sensor, high temperature circuit
- Coolant temperature sensor, high temperature circuit
- Coolant level sensor, high temperature circuit
- Coolant pressure sensor, low temperature circuit
- Coolant temperature sensor, low temperature circuit
- Coolant level sensor, low temperature circuit
- Accelerator pedal position sensor x2

- Barometric pressure sensor
- Camshaft sensor
- Crankshaft sensor
- Crank case pressure sensor
- Oil level sensor
- Oil filter clogging sensor
- Oil pressure switch
- Oil temperature sensor
- TMAP sensors x 2

9.2.16 Data Logging

The Input Panel (IP) will be expected to provide logged data for access by the operator for purposes such as diagnostic fault finding. The ECU will support this functionality by providing the data to be logged to the IP. The data will be shared using the MiLCAN/ J1939 interface. The number and logging rate of signals will be limited by the available bus load and ECU/IP computing capacity.

9.2.17 Electrical and EMI/EMC

The EMS will be compliant with the electrical power supply requirements defined in MIL-STD-1275E, but shall operate on a voltage range of 9-36V DC (which is a larger voltage range than defined in MIL-STD-1275E).This standard defines protection requirements for overvoltage, reverse polarity, transients, etc.

The EMS will be compliant with the EMI & EMC requirements defined in MIL-STD-461G.

9.2.18 Engineering Development

The ECU will support online calibration of the EMS parameters using an engineering calibration tool, such as ETAS INCA, on an engineering laptop connected using an Ethernet cable and communicating via, for example, XCP. This will allow the calibration of all control parameters associated with the functions outlined in this document.

The ECU will support flashing of new control software using a software tool provided by the Supplier.

9.2.19 Fording

The vehicle will be capable of performing fording operations up to a depth of 5m. In order to maintain the safety of the occupants, when the fording switch is ON the ECU will carry out the following actions:

- Inhibit shutdown from any source e.g. both from IP and from ECU control logic (if necessary, the operator will still be able to perform emergency shutdown)

If the engine stops running for any reason whilst the fording switch is active and ECU is still powered (i.e. the operator hasn’t commanded emergency stop), then the ECU will attempt to restart the engine automatically.

9.2.20 Fix Speed Operation:

The ECU shall support ‘fixed-speed’ operation via designated hardwired digital inputs. The speed set points shall be configurable. The Project preference is for three fixed-speed hard wired inputs to be made available, although two speed set points may be deemed acceptable – to be discussed during the Project Development phase.

9.2.21 Instrument Panel (Display Unit) requirements (As Applicable)

The typical engine diagnostic parameters required by VCU from ECU are as follows

1. Engine Speed, rpm
2. Throttle signal / Pedal Position.
3. Engine oil pressure in bar
4. Low engine oil pressure warning
5. Engine coolant temperature
6. Engine oil temperature
7. Engine fuel temperature.
8. Charge air temperature.
9. Engine start lock.
10. Air filter warnings
11. Low fuel rail pressure warning.
12. Engine hours.
13. Engine revolution count.
14. Engine emergency shutdown.
15. High Coolant temperature warning.
16. Coolant temperature low warning.
17. Coolant flow failure warning.
18. Coolant level 1 warning
19. Coolant level 2 for engine shutdown.
20. Throttle / pedal signal failure
21. Barometric pressure
22. Actual engine torque.
23. Demand engine torque.
24. Engine derating status.
25. Engine override information.
26. Fuel rate.
27. Fuel economy.
28. Rail pressure.
29. Malfunction codes for sensor failures, injector failures etc.
30. BITE (Built In Test Equipment) status
31. Real time clock information

9.2.22 ECU Hardware Robustness

The ECU will meet the following environmental and robustness requirements for qualification.

QUALIFICATION ENVIRONMENTAL TESTS

Order of Testing	TEST NAME	SPECIFICATION	REMARKS
1	Environmental Stress Screening (ESS)	12 number of cycles (8 defect free cycles) shall be done so that total duration at high temperature and at low temperature will be at least 1260 minutes respectively. Each thermal cycle should be done as per figure enclosed in Appendix - 'L'. After completion thermal cycling random vibration to be carried out.	1. System ON during positive cycle and System OFF during the negative cycle. 2. Limited Performance check during each positive cycle of the test when the unit is inside the chamber. 3. Performance check after recovery.
2	Vibration Test	Random Vibration in 3 axis $10(m/s^2)^2/Hz$ during 20 to 500 Hz falling to 1 $(m/s^2)^2$ / Hz at 2000 Hz for 2 hours in each axis.	1. System ON during the test 2. Limited Performance check during the test. 3. Performance check after recovery
3	High Temperature (Operational) (*)	100^0C +/- 3^0C for 24 hours	1. System ON during the test 2. Limited Performance check during last half an hour
4	High Temperature (Storage) (*)	85^0C +/- 3^0C for 24 hours.	1. System OFF during the test 2. Performance check after recovery
5	Low Temperature	-30^0C +/- 3^0C for 24 hours.	1. System OFF during the test 2. System ON during last half an hour 3. Limited Performance check during last half an hour 4. Performance check after recovery
6	Damp Heat	40^0C +/- 2^0C for 16 hours. RH > 95%	1. System OFF during the test 2. Performance check during last half an hour
7	Drop Test	Height of drop = 100 mm; No of drops/face = 1 on all faces except connector side.	1. Performance check after test
8	Dust Test	Chemical Composition: SiO_2 : 97 – 99% Fe_2O_2: 0-2% : Al_2O_2:0 to 1% : TiO: 0 to 2% : MgO : 0 to 1% : Ignition Losses : 0 to 1% One hour. temp 40^0C+/-3 RH < 50%	1. Performance check after recovery
9	Bump Test	4000 bumps at 25 g; pulse duration: 6 ms, half sine wave.	1. System OFF during the test 2. Performance check after recovery
10	Shock Test	40 g, 2 shocks per direction, Pulse duration : 18 ms.	1. System OFF during the test 2. Performance check after recovery
11	Water Immersion Test	6 meter water column depth (Pr - 58.7 kPa), Duration 2 hours	1. System OFF during the test 2. Performance check after recovery
12	Mould Growth Test	30 ^{0}C +/- 1 ^{0}C and RH > 90 %, Duration: 28 days(Test No.21).	1. System OFF during the test 2. Performance check after recovery
13	Salt Spray Test	35^0C +/- 2^0C, RH 90 - 95 %, Duration 3 days (Test No: 9, Procedure 2).	1. System OFF during the test 2. Performance check after recovery
14	Contamination Test	One or more of the following contaminating fluids to be sprayed - Paraffin, Petrol, Lubricating oil, Hydraulic fluids and Ester based lubricating oils. After spraying, maintain temperature 50°C for 48 hrs	1 . System OFF during the test 2. Performance check after recovery

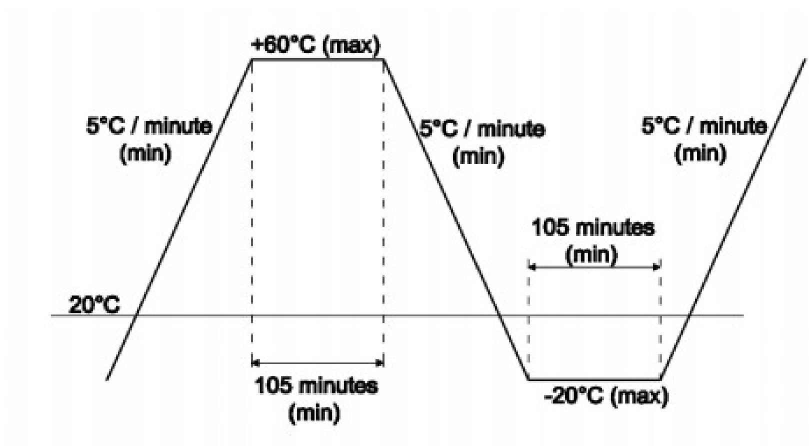
(*) Applicable for systems fitted in Engine Compartment. For systems fitted outside engine compartment, High temperature (operational) is 55^0C and High temperature (Storage) is 85^0C

Note: Tests 2 to 14 are to be conducted as per JSS 55555: 2012 rev3, L2J and L3 class

APPENDIX-'L'

Environment Stress Screening (ESS)

Burn-in-test



Burn-in-test: Thermal cycle shall be as follows (MIL STD 2164):

- 12 number of cycles shall be done so that total duration at high temperature and at low temperature will be at least 1260 minutes each
- After completion of thermal cycling Random Vibration test to be carried out as follows:
  - Random Vibration on 3 perpendicular axis.
  - 10 (m/s2)2/Hz during 20 to 500 Hz falling to 1 (m/s2)2 /Hz at 2000 Hz for 2 hours in each axis.

10 DELIVERABLES:

10.1 Parts:

The parts to be delivered as given in the **Section 8.2**.

10.2 Documentation & Certificates:

The documents to be delivered as given in the **Section 8.1, 8.3 & 8.4**.

11 WARRANTY:

Parts to be replaced against any manufacturing defects.

The applicable warranties for the kits are 30 Months from the date of supply and acceptance by BEML.

12 GENERAL GUIDELINES:

12.1 The firm should submit a detailed technical proposal comprising the following points:-

a) Development approach for the activities mentioned in scope of work, if any.

b) Duration required by the firm for executing the development work.

c) Financial background and stability including detailed audited financial statements for the last 5 years.

d) Details of warranty practices and services in after sales, number of years for which Spares and Service support offered to customers.

e) Suppliers base, leverage and relationship.

f) Additional services the Company can offer.

g) Have the firm executed any joint development program to any customer? If yes, please furnish the details.

12.2 The following details should be submitted

a) Company profile, giving details of current activities and management / personnel structure including evidence of incorporation.

b) Willingness letter for supplying of parts for proto (5 Set) Batch, and serial production for minimum of 30 years.

c) The firm should have executed similar assignment with at least 3 year experience of similar work.

d) Highlight the infrastructure available / modalities to take up the project.

e) Any other relevant information considered necessary for successful implementation of the proposed scope of work.

f) Document / Report on core expertise in the following areas of work:

a) Capability on Design and development of CRDI system & ECU for CRDI engine

b) Sourcing of components

c) Design updates and re-sourcing of parts

d) Quality assurance and testing

f) Facility for pass off test of production ECU's.