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GOVERNMENT OF INDIA
MINISTRY OF RAILWAYS

TECHNICAL SPECIFICATIONS FOR DESIGN & DEVELOPMENTAL WORK "REDUCTION OF EXHAUST EMISSIONS FROM DIESEL LOCOMOTIVES OF INDIAN RAILWAYS"

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INTRODUCTION

Research Designs and Standards Organization (RDSO) under Ministry of Railways at Lucknow is the central research organization of Indian Railways (IR) and headed by Director General, RDSO. Director General is assisted by Additional Director General, Sr. Executive Directors and Executive Directors, heading different directorates. RDSO has various directorates for smooth functioning including the Engine Development Directorate (EDD). EDD is engaged in design and development of railway traction diesel engines and has CAD, engine simulation and computer centre, dedicated engine test cells, fuel injection lab, instrumentation lab and other facilities to carry out diesel engine development work.

EDD has taken up projects to reduce the emissions from diesel locomotives of Indian Railways Optimizing the engine parameters and modification to the engine design to achieve emission levels (HC, CO, NOx, PM & Exhaust smoke) as per International Standards

The Work has been planned for completion in two phases.

Phase-I Concept study (already completed)

Phase-II Detailed engine design

Phase 1 with preliminary design analysis for following parts of ALCO 251 and 251+ engines has been completed -

i) Fuel Injection Cam
ii) Stiffer Unit Camshaft
iii) Cylinder head bolts and Cylinder head
iv) Cylinder Liner
v) Piston and Pin
vi) Connecting Rod
vii) Crankshaft Bearing & Crankshaft Strength
viii) Engine Crankcase
ix) Valve Train

In view of the expected improvements in emissions, above components of ALCO 251 and 251+ engines would need to be optimized. Details about the diesel engines are given in Annexure 1.

OBJECTIVE OF THE PROJECT

The objective of this project is to develop a kit for retro fitment on existing engines, and for manufacture of new engines, in order that the engines become US EPA Tier 1 compliant. This must be done without increasing the peak cylinder pressure of the engine (limit is 125 bar) and without adversely affecting the brake specific fuel consumption. An improvement in the bsfc is a sought objective.

Following route has been identified during the feasibility phase of the project: -

- Fuelling
  - Increase fuel injection pressure
  - Timing retard (level of retard is balanced with injection pressure increase)

- Breathing
  - Valve timing modified to increase trapped AFR
  - Improve charge cooling
  - Boost pressure increase
  - Port efficiency increase (if required after above changes)

- Combustion
  - Injection nozzle
  - Piston bowl geometry
  - Compression ratio

Based on the feasibility report, following route for development of US EPA Tier 1 compliant locomotive engine is being considered

Development of US EPA Tier 1 emission standard compliant diesel locomotive engine

It is proposed to develop a suitable retrofit able kit for the existing fleet of ALCO design diesel locomotives operating on Indian Railways network. Same kit will be used for manufacture of the new locomotives and during their rebuild at Diesel Component Works, Patiala.

Design of the following components are not planned to be changed: -

- Engine block
- Crankshaft
- Connecting rod

Changes/ modifications are envisaged in the design of the following components

Table 1: Details of the scope of work and deliverables

Sn	Component	Work required	Responsibilities	Deliverables
1.	Electronic fuel injection system 18 mm/ 20 mm dia plunger along with modified fuel cam to suit	1. EDD has developed a 1-D thermodynamic model of the ALCO engine (in Ricardo WAVE) during the feasibility phase of the project. It will be required to choose between the 18 mm & 20 mm plunger diameter fuel injection pump to increase the MEIP. Use of the existing thermodynamic model to decide the most suitable plunger size. (These sizes are offered by the fuel equipment supplier to EDD). 2. A new fuel cam is to be developed to suit the 18/ 20 mm dia plunger EFI pump.	1. Contractor to guide EDD in modification of the 1-D thermodynamic model in order to take a decision on the 18 mm vs 20 mm plunger dia. 2. Contractor to develop the new fuel cam profile and guide and support during its manufacture and validation and iterating the design in case situation so warrants. 3. Contractor to guide EDD in developing suitable design of experiments and during calibration of the ECU of the EFI. 4. Contractor to guide EDD during validation of the EFI and help solve any problems arising during the validation.	1. Modified WAVE model. 2. Report on the findings of the WAVE model with recommendations for fuel pump diameter size. 3. Design analysis, design drawing and manufacturing drawing of the new fuel cam profile. This fuel cam profile should be suitable with air and exhaust cam profile with miller cycle timing camshaft. 4. Manufacturing support during manufacture of the fuel cam. 5. Scheme for design of experiments for ECU calibration. 6. Guidance and support in terms of email, telephone and web conference during validation of the camshaft and later during validation of the complete emission reductions kit on the engine test bed at RDSO and on the Locomotive.
2.	High pressure injectors and 12.5 compression ratio steel cap pistons	1. A new high pressure injector has already been developed by the fuel equipments supplier. Also a KIVA 3-D model is being developed for the ALCO engine combustion chamber. It will be required to see the	1. Contractor will be modifying the KIVA model to carry out the compatibility study and bring out the injector nozzle hole geometry and the piston bowl geometry optimisation. 2. EDD will get the modified injector and	1. Modified KIVA model. 2. Report on the findings of the KIVA model with recommendations for injection hole geometry and piston bowl geometry. 3. Design analysis, design drawing and manufacturing drawing of the new high pressure injector nozzle

		compatibility of the high pressure injectors with the 12.5 CR pistons for optimum fuel efficiency and emissions. As a result of above analysis if any changes to the injector nozzle holes/ configuration or to the piston bowl profile are required, the same will need to be done and validated on the engine test cell of EDD.	piston manufactured through their suppliers. 3. Contractor will support during engine testing and validation of the new designs at EDD test cells and also iterate in case required.	and piston bowl geometry. 4. Manufacturing support during manufacture of the high pressure injectors and piston. 5. Guidance and support in terms of email, telephone and web conference during validation of the high pressure injector and piston on the test bed and later during validation of the complete emission reductions kit on the engine test bed at RDSO and on the Locomotive.
3.	Miller timing turbocharger along with camshaft to suit these timings	1. EDD is already in the process of development of a Miller timing turbocharger. Initial thermodynamic simulations have shown that with the Miller timing turbocharger the fuel efficiency can be enhanced, the emissions reduced without increasing the peak cylinder pressures of the engine. 2. KIVA model as mentioned earlier is being used to validate the results of the 1-D thermodynamic model.	1. Contractor will be responsible for modifying the 1-D thermodynamic model of the engine to incorporate the new turbocharger data and carry out simulations to generate performance, emissions data and to guide the EDD personnel in verification of the same on the engine test cell of EDD. 2. Contractor should also verify the effect of a modified exhaust manifold (if any) as detailed in para number 6 in association with the turbocharger supplier.	1. Modified WAVE model, report and recommendations on the WAVE model to be clubbed with item no. 1 above. 2. Turbo-matching on the 1-D model in association with the turbocharger manufacturer in case there is change in the exhaust manifold. (Output of this report will be used by the turbocharger manufacturer for him to modify his turbocharger in case required)

4.	Higher effectiveness after cooler	1. It is required to develop a high effectiveness after cooler for the turbocharger. Preferably a plate type after cooler. EDD is in discussion with a local supplier in India for the same. The local supplier has developed an all aluminium plate type after cooler but this has material compatibility issues with the coolant.	1. Contractor will be required to locate suitable aluminium alloy to overcome the material compatibility issues with the coolant. Check the suitability of the design and effectiveness and support and guide in case any modifications to the design are required.	1. Check the design through suitable simulation model in GT Cool and support in reiteration and submit report. 2. Model of the simulation along with inputs, outputs (all boundary conditions). 3. Correct material specification of the aluminium alloy and support during design validation (laboratory tests) and field verification. Support will be in form of email, telephonic conversation and web conference.
5.	Design of a separate after cooler cooling system along with modification of the engine cooling system to suit this separate after cooling. Design of an electrically driven forced ventilation engine cooling system to support the separate after cooling system and to enhance the cooling capacity of the present system.	1. At present, the after cooler of the turbocharger is water cooled and the engine and the after cooler share the same water circuit. 2. It is required to design a separate cooling system for after cooler along with modification of the engine cooling system to suit this separate after cooling. (LTA). 3. It is required to design an electrical driven forced ventilation engine cooling	1. Contractor is required to carry out the design of the separate after cooling system along with the modification/ design of the present engine cooling system to suit separate after cooling system. This will include after cooler sizing, its design, engine radiator design modification, pump sizing, additional pump etc. 2. Contractor shall guide and support during design verification and validation on the engine test bed and during field trials and carry out design iterations as per requirement.	1. Develop design through suitable simulation model in GT Cool and support in reiteration and submit report. 2. The manufacturing drawings and specifications for cooling system elements for separate after cooling circuit broadly consisting of:- a. Pump(s) b. Heat Exchanger(s) c. Location of heat exchangers (e.g. merge within the envelope of the existing radiator) d. Piping and plumbing

				e. Electrical drive for the radiator fan f. Radiator fan g. Radiators 3. Model of the simulation along with inputs, outputs (all boundary conditions). 4. Support during manufacture, lay-outing, validation and verification of the separate after-cooling system on the test bed and on the locomotive.
6.	Sizing of the exhaust manifolds	1. Present ALCO engine exhaust manifold is designed for a power rating of 2600 hp. It was possible to develop the 3100-3600 hp rating engine without any changes to the exhaust manifold. However a sizing of the exhaust manifold is required to know whether any increase in diameter or other changes are required. 2. Objective is to ensure easy breathing of the engine and good matching with turbocharger.	1. Contractor will evaluate the design of the exhaust manifold with the help of the 1-D thermodynamic model already created and make changes if required. 2. Contractor will guide and support during manufacture, verification and validation of the new design.	1. Check the design through suitable simulation model in WAVE Model and support in reiteration and submit report. 2. Model of the simulation along with inputs, outputs (all boundary conditions). 3. The manufacturing drawings and specifications of the exhaust manifold if the design of the exhaust manifold requires a change. 4. In case of a modified exhaust manifold, Support during manufacture, lay-outing, validation and verification on the test bed and on the locomotive. 5. In case no change is required in the exhaust manifold then the tenderer should

				support during verification on the test bed and on the locomotive.
7.	Intake and exhaust ports modification of the cylinder head	1. In the feasibility report, the consultant has suggested that in case the above measures are not sufficient, modification of the intake and exhaust ports of the cylinder head may be required. 2. It is therefore intended to take up the analysis and modification of the intake and exhaust ports of the cylinder head.	1. The contractor is required to analyse and make suitable design of the intake and exhaust ports. He may use suitable CFD software for the purpose. EDD can provide detailed 3D models in UG of the existing cylinder head. 2. Contractor will be required to guide and support during manufacture, verification and validation of the cylinder head and carry out necessary iterations.	1. A running CFD model of the cylinder head in standard CFD software like Fluent etc. including all input and output data and boundary conditions. 2. Report on the analysis of the CFD model and recommendations for design change. 3. Detailed drawings and specifications of the modified cylinder head. 4. Support during manufacture, lay-outing, validation and verification of the modified cylinder head on the test bed and on the locomotive.

Process of development

1. Signing of Contract.
2. Design and development of the components/ sub-systems/ systems as per the above list and based on the feasibility report recommendations. This will include CAD work (3-D and 2-D), 3-D CFD and combustion CFD simulations, fuel injection simulations, Finite element analysis, design of experiments etc. as required. The output of this activity shall be in the form of 2-D manufacturing drawings and manufacturing specifications to be used by the manufacturers to produce the prototype parts. The CAD work including development of 3-D models and detailed 2-D manufacturing drawings shall be done by RDSO EDD under guidance of the contractor. RDSO EDD staff shall be involved at every step of the design and development process including building models for simulations, deciding specifications including functional and detailed manufacturing specifications, etc. either physically at contractor's premises or through web based interactions even on a daily basis if required.
3. If the tenderer uses any software not available with EDD he will provide access for the same to EDD personnel during currency of the project.

4. Manufacture of the prototype by the manufacturers (order to be placed by RDSO) under supervision of RDSO and with expert guidance from the contractor/ consultant.
5. Type test of the prototype components at manufacturers premises under supervision of RDSO with expert guidance from the contractor/ consultant.
6. Test bed trials of the complete kit on the Engine Test Bed at RDSO including Turbocharger rematching to engine to the changed engine configuration – This activity shall be carried out on the engine test beds at RDSO EDD. This will involve but not limited to framing of Design of Experiments and detailed mapping of the engine in terms of bsfc, emissions, temperatures and pressures. Consultant will guide RDSO for developing the DOE matrix.
7. Fitment of the prototype kit on a diesel locomotive at DMW Patiala, India under supervision of RDSO and expert guidance of the consultant.
8. Testing of the above kit fitted diesel locomotive at DMW Patiala under supervision of RDSO and expert guidance of the consultant. This will include emission testing of the kit fitted diesel locomotive for compliance to US EPA Tier 1.
9. Field trials of the kit fitted diesel locomotive.

Manufacturing of prototypes

The contractor shall plan to develop designs for at least one but not more than two alternate prototypes. EDD shall place order on the suppliers and the contractor shall guide and support during manufacture, verification and validation of the designs.

Limits of performance, emissions etc.

The existing fabricated engine block/ crankcase of the 3100 hp rated ALCO 16 cylinder is rated at 125 bar PCP. The contractor should ensure that the PCP should not exceed this limit without any detriment to in-vogue fuel efficiency of the engine (156 gm/bhp-hr). Envelop constraints of the locomotive may be observed.

Deliverables

1. All deliverables as given in Table 1 above.
2. 3-D and 2-D detailed drawings including manufacturing drawings and specifications of components, sub-assemblies, assemblies developed during the course of the work as given in Table 1 above and any additional which arise out of the course of the project.
3. All detailed material specifications.
4. All Test specifications
5. All Apparatus Instructions
6. All simulation models and accompanying data at every stage
7. Design details including all WHYs and HOWs
8. All documents in hard and soft copies
9. One set of all reference books, technical papers, Standards, reports used if not confidential.

Annexure-1

Engine Data – 16 Cylinder DLW built 251-B ALCO engine

1.	Application	Rail traction diesel (Indian Railways, Broad gauge) 3300 HP, 3600 HP for DG Set
2.	Engine type	DLW built 251-B engine
3.	No. of cylinders	16
4.	Configuration	'V'
5.	Cycle	4 stroke
6.	Bore	9"(228.6 mm)
7.	Stroke	10.5"(266.7mm)
8.	Compression ratio	11.75:1
9.	Ratio of con rod length to crank radius	4
10.	Fuel injection (at full load)	
	Spill port closing	22.0 degree CA BTDC
	Duration of injection	Approx.34 degree CA
	Pumps	17 mm plunger dia, 20mm stroke
	Nozzles	0.35 mm dia. 9 holes, 157-degree spray angle, 90-degree tip angle.
11.	Firing order	1R 1L, 4R 4L, 7R 7L ,6R 6L, 8R 8L, 5R 5L, 2R 2L, 3R 3L
12.	Valves (4 valve head) Air inlet open	80.1 degrees CA before TDC
	Air inlet close	35.4 degrees CA after BDC
	Exhaust open	57.7 degrees CA before BDC
	Exhaust close	57.7 degrees CA after TDC
	Valve dia	7.62 cm
	Max. valve lift	2.04 cm
	Port diameter	7.40 cm
13.	Turbocharger	One per engine
14.	After cooler	Single/twin, water-cooled.

Engine performance data at full load- 16 Cylinder DLW built 251-B engine

1.	Brake horse Power	3100HP	3300 HP	3600 HP
2.	Engine speed	1050 rpm	1050 rpm	1050 rpm
3.	BMEP	14.25 bar approx.	15.75 bar approx.	17.17 bar approx.
4.	BSFC (Corrected $60^{o}F/15.55^{o}C$)	151 gm/BHP hr	151 gm/BHP hr	151 gm/BHP hr
5.	Turbo inlet temperature	$485^{o}C$ (approx.)	$500^{o}C$ (approx.)	$535^{o}C$ (approx.)
6.	Average cylinder head exhaust temperature	$350^{o}C$ (approx.)	$350^{o}C$ (approx.)	$350^{o}C$ (approx.)
7.	Max. Ambient temp. Expected	$55^{o}c$	$55^{o}c$	$55^{o}c$
8.	Specific air consumption	4.5 kg/sec. approx	6.5 kg/sec. approx.	6.54 kg/sec. approx.
9.	Vacuum at compressor air intake		400 mm H2O-g approx.	550 mm H2O-g approx.
10.	Compressor outlet pressure	1.60 bar-g approx	1.82 bar-g approx.	2.06 bar-g approx
11.	Pressure drop across after cooler	0.1 bar approx.	0.1 bar approx.	0.12 bar approx.
12.	Inlet manifold pressure (engine air gallery)	1.55 bar approx.	1.77 bar approx.	2.02 bar approx.
13.	Exhaust pressure before turbine	1000 mm of Hg approx	1000 mm of Hg approx.	1120 mm of Hg approx.
14.	Turbine outlet pressure (Exhaust)	440 mm H2O g approx. on engine test bed	440 mm H2O g approx. on engine test bed.	640 mm H2O g approx. on engine test bed.
15.	Maximum cylinder pressure	1800 psi.	1800 psi.	1950 psi.

NOTE: These figures are indicative and can be used only for approximate guidance

Exhaust Manifold Data

1.	No. of cylinder discharging in to one turbine entry pipe	16
2.	Firing interval of cycle discharging in one turbine entry	22.5 degree
3.	Exhaust manifold volume / Turbine entry	-
4.	Number of entries / Turbine	Three / One

Typical Indian Railway operating duty cycle for diesel locomotives

NOTCH	FREIGHT SERVICE %	PASSENGER SERVICE %
Idle	60	49
1st	3	6
2nd	5	7
3rd	3	5
4th	4	4
5th	4	7
6th	5	5
7th	6	5
8th	10	12

*Extracted from RDSO report no.-MP-Misc. – 204, Feb. – 2008

Operating point at various notches for Alco 251B engine

NOTCH		3100 HP		3300 HP		3600 HP	
	RPM	LOAD (N)	POWER (HP)	LOAD (N)	POWER (HP)	LOAD (N)	POWER (HP)
8th	1050±3	21600±50	3100	22997±50	3300	25065±50	3600
7th	950±3	19082±50	2500	20316±50	2640	22163±50	2880
6th	850±3	16018±50	1870	17029±50	1980	18577±50	2160
5th	750±3	13826±50	1430	14475±50	1485	15971±50	1620
4th	650±3	10616±50	950	11135±50	990	12147±50	1080
3rd	550±3	8138±50	615	8773±50	660	9570±50	720
2nd	450±3	5471±50	330	5361±50	330	5848±50	360
1st	350±3	2984±50	145	3336±50	165	3760±50	180
Idle	350±3	2131±50	105	2131±50	105	2131±50	105

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