Development of a Common Rail Electronic Direct Injection (CReDI) Fuel System for a Four stroke ALCO V-16 Rail Traction Diesel Engines

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Abstract- Similar to progression in automotive technology from carburetted engines to multi point fuel injection technologies, to save fuel over the diesel traction, a Common Rail Electronic Direct Injection (CReDI) fuel injection system for railroad application has been developed for ALCO engines at Research Designs and Standard Organization, Indian Railways (IR), Lucknow. CReDI system offers flexibility of modulating fuel injection pressures coupled with dynamic start of injection at each power setting, designated as locomotive engine notch. This flexibility in the system is independent of engine rpm and its values decided after detailed fuel mapping on an engine test bed. Injector geometry for CReDI is selected through simulation, experimentation and verification studies for spray angle and sauter mean diameter of the fuel droplet, so as to enhance combustion efficiency. CReDI wet components comprising of injectors, high pressure pumps, common rails etc. are mounted on the engine itself and are controlled through an electronic engine management system harmonized with the traction control system of the locomotive. Mechanical integrity and compatibility of the CReDI system vis a vis other engine sub assemblies is proven and system designed within operational limits of the power pack. CReDI system is considered as both a retrofit and a new manufacture solution for replacement of the exiting mechanical fuel injection systems being used on IR diesel locomotives. Besides fuel savings over the traction duty cycle, use of CReDI system results in lower carbon dioxide emissions and other key engine exhaust stack emissions like hydrocarbons, oxides of nitrogen, carbon monoxide, particulate matter etc.

II. COMMON RAIL ELECTRONIC DIRECT INJECTION FUEL SYSTEM

CReDI system consists of a high pressure pump that raises the fuel pressure in a single stage from the nominal feed pressure up to the specified system injection pressure. This fuel is then distributed to individual injectors via a distribution gallery or rail. Injection timing and quantity metering are effected at the injector by electronic control. Drive for the high pressure pump selected in its application by IR is mechanical and is driven through a pinion assembly mated with existing cam gears provided on the engine. The rail is double walled construction suitable to withstand pressures up to 2000 bar. Electric motor driven low pressure fuel pump raises the pressure of the side walls of the engine crankcase. These fuel injection pumps are actuated through fuel cam lobes on the camshaft with help of mechanically driven cross head lifters to pressurise the fuel. Pressurised fuel is delivered to individual injectors fitted on cylinder heads through high pressure pipes. The fuel injection pump is a jerk type pump with a helix designed on its plunger assembly to control metering of fuel and start of injection of the fuel. Start of injection is optimised for rated power and is nearly fixed for all engine notches. Fuel is injected into a quiescent combustion chamber. Penetration of the injected spray is dependent on the injection characteristics of the injector geometry & injection pressure. Rate of fuel injection pressure is controlled through the fuel cam profile and is fixed. Literature indicates [1] that from the point of view of good power and fuel economy, combustion should take place so that the peak firing pressure occurs at about 10-15° after the top dead center of piston travel.
fuel flowing from fuel tank and delivers to the high pressure pump through fine filters. Existing engine filtration has been augmented to meet close tolerances of the wet components. External dimensions of the CReDI injector have been kept identical to those of mechanical fuel injectors as provided and do not require any major modification in the cylinder head for its fitment. Fuel injectors are mounted with solenoid valves, controlled through inputs from the Electronic Control Unit (ECU) and have an inbuilt individual accumulator of sufficient reserve volume to meet requirements of injected fuel per stroke satisfactorily. A wave dynamic dampening mechanism has been provided in the inlet stud of the common rail injector. CReDI system has been designed to make it suitable for rail traction service characterized by a wide, fluctuating, cyclic load pattern and extended intervals of operation at idle & full load. It is sturdy in operation and incorporate components that can withstand the hostile environmental conditions in the engine room such as dust, water, fuel/lubricating oil, vibration, high temperatures, electrostatic/ electromagnetic interference, and a noisy power supply. Common rail injectors are fitted inside the cylinder heads where temperatures reach approximately to 150-200°C.

III. FUNCTIONS PERFORMED BY COMMON RAIL ELECTRONIC DIRECT INJECTION FUEL SYSTEM

CReDI system takes over the following existing functions of the engine governor and the over-speed trip mechanism. Precise control on diesel fuel injection timing, fuel quantity and injection pressures at each notch position. Independent forming of opening and closing flank of the diesel fuel injection rate. It maps injection timings with respect to load, speed, boost air pressure etc., to achieve lowest fuel consumption and enters into low idle mode of the engine operation without driver's intervention. It enables a superior engine speed control and holds the engine speed within ± 5 rpm of the required speed at all speeds and loads under steady state conditions without any signs of hunting or overshooting. It has built-in diagnostics and runs a full self-diagnostic on every power-on and at regular intervals while the engine is in operation. This operation is transparent, and does not affect the normal working of the system. All faults are logged for later downloading to a PC by the maintenance staff and major fault conditions are indicated by suitable indicators mounted on the controller itself.

IV. METHODOLOGY ADOPTED FOR DESIGN VERIFICATION TEST OF CREDI SYSTEM ON AN ALCO ENGINE

After the design & development of the CReDI system, design verification tests were carried out on engine test bed at RDSO, Lucknow to establish performance against the design objectives of reduction in fuel consumption and engine exhaust stack emissions. Following speed and torque curve was followed for engine loading on the test bed. Detailed fuel maps were created for the CReDI system on test beds adopting sweeps on injection pressure and start of injection on individual notches.

Figure-1 Speed-Torque curves

Baseline test was carried out with existing mechanical fuel injection system at rated power on test bed. Performance runs were done and data averaged removing outliers/transients and summarized for performance and emissions. Various test parameters were recorded with use of a high speed data acquisition system of M/s AVL. Standard horsepower was used to arrive at duty cycle fuel consumption for base line. Similar power levels were observed for configurations of CReDI for comparison. After base line testing, existing mechanical fuel injection system was removed and CReDI system fitted on the test engine. All other components of the engine were kept identical. Base line duty cycle fuel consumption was calculated in both freight and passenger duty cycle. CReDI injector geometry was designed
based on simulation and test bed verifications results and testing done. Mechanical integrity and compatibility of the ALCO CReDI system was successfully proven on the test bed. Fuel consumption on the engine was measured using an accurate Coriolis based fuel measurement equipment and correction factors used as per ALCO standard correction formulas to arrive at brake specific fuel consumption at individual notches and over the duly weighted traction duty cycle. It was seen that bsfc with CReDI system is much lower than the mechanical system. Higher reductions were observed at lower and intermediate notches indicating improved combustion efficiency due to a dynamic start of injection and intake pressure modulation.

Gaseous measurements were made using gaseous measurement equipment AMA-4000 and smoke meter-437 of M/s AVL. Emissions reduction was calculated as per tendered IR duty cycle using standard gaseous conversion factors as per EPA for both freight and passenger duty cycles. It was seen that CReDI system indicated a reduction in oxides of nitrogen by more than 15 % over both IR freight and passenger duty cycles as compared to mechanical base line and carbon monoxides indicated a reduction of more than 42% over both IR freight and passenger duty cycles.

Smoke opacity of the engine fitted with CReDI system as well as with conventional mechanical fuel injection system was measured by Smoke meter-437 of M/s AVL. Use of CReDI system has shown a drastic reduction in smoke opacity over the duty cycle.

V. CONCLUSION

It is seen that the fuel efficiency of ALCO 16V engine fitted CReDI system is better than the conventional mechanical fuel injection system. Harmful emissions, noise pollution and smoke are also reduced with this system. Electronic control system enables precise injection timing, rail pressure etc. The powerful microcomputer control system makes the whole system more perfect and reliable.

REFERENCES

2. Luthra S.K., Development of fuel injection systems for diesel engines with dynamically varying timings.