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Technologies adopted in Diesel Locomotive Engines over Indian Railways

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Abstract: *Indian Railways operates 12000 trains everyday and half of them are hauled by the diesel locomotives. There are currently two types of locomotives being used over Indian Railways, the four stroke American Locomotive Company locomotives (ALCO) and the two stroke General Motors Electro Motive Division locomotives. There are commonalities as well as differences in these two locomotive engine technologies (EMD).For the past 6 decades ALCO locomotives are serving the nation and past 2 decades EMD locomotives are pressed into service. Salient features of these two technologies are not compared and as such this paper is an effort to compare the two engine technologies. All the major issues pertaining to locomotive engines are being compared in detail to have a good information of the same for a fair comparison. The paper includes the data made available by these two loco manufacturers originally from USA as well as data from diesel locomotive works, where they are currently under production.*

Keywords: *American Locomotive Company, Diesel Locomotive Engines, Diesel Locomotive Works, General Motors Electro Motive Division, Indian Railways*

I. Introduction

Indian Railways (IR) is India's lifeline. IR is involved in movement of men and materials from one part of the nation to the other part covering majority of the population since 1853. Indian Railways commenced with steam traction in 1853 wherein 3 steam locomotives hauled the first train service. Due to development of diesel locomotives which had better efficiencies, speed, lesser maintenance requirements, the steam traction was discouraged and diesel locomotives were put into service. Post independence IR was nationalised and India entered into technical agreement with American Locomotive Company (ALCO) of USA and a diesel locomotive manufacturing unit was established at Varanasi in Uttar Pradesh. Initially 12 locomotives were imported from USA and due to technology transfer agreement IR started manufacturing these locomotives. These locomotives were basically 16 cylinder four stroke locomotives with turbochargers and developed 2600 hp. More than 3000 Alco locomotives have been manufactured by Diesel Locomotive Works Varanasi so far. ALCO was started in USA during 1903 and was defunct by 1969. IR has gradually increased the share of indegenisation of ALCO loco engines over the years. Due to transfer of technology the locomotives of ALCO design were continued to be manufactured by IR till the introduction of GM locomotives in 1999. In the meanwhile a new production unit viz. Diesel loco Modernisation works was established by IR at Patiala in Punjab to undertake the upgradation and rebuilding/ mid life rehabilitation of the ALCO locos. The upgradation involved enhancing the engine output from 2600 hp to 3100 hp and later 3300 hp. Various measures were included to increase the power output viz. Improved turbo supercharger, double helix fuel injectors for higher fuel injection , incorporating electronics in the form of sensors, micro controllers, among other measures.

In the recent decade IR entered into technical understanding with General Motors of USA to manufacture state of art two stroke engine locomotives with AC –AAC technology (AC generation and AC traction motors). These are high powered engines which develop 4000 hp and have received wider acceptance due to increased maintenance periodicity and higher reliability. Originally few locomotives were procured in assembled condition itself and then there was technology transfer and IR commenced manufacturing these locomotives at DLW Varanasi and increased the indigenous content. During 2014-15 IR has upgraded these locomotives and now WDG 5 5000 hp locomotives are undergoing trails. The original single cab design of the GM EMD locomotive was posing visibility issues especially during long hood driving and hence IR has accordingly commenced manufacturing the locomotives with wider cab design and now twin cab locomotives have been put into service. These locomotives have self load capabilities which mean that we can start the engine and test the power developed by the engines for various rpm without the need for external load box thus saving time for maintenance.

As on 2013-14 IR has 5232 Diesel Locomotives, 4823 Electrical locomotives and 30 Steam locomotives in its fleet [1]. The Gross tonne km hauled all over IR during 2012-13 in terms of percentage was

49% by Diesel, 51% by Electrical locomotives [2]. IR during 2014-15 spent Rs 35,474 Crores towards its demand for purchase of diesel and electricity. [3]. The cost of ALCO loco is Rs 7 Crores and EMD loco is Rs 15 Crores and as such maintenance of these locomotives for reliable service is a big challenge [4] This paper is an attempt to bring out the salient features of the two engines by way of their similarities and striking differences. Also the various developments undertaken by IR over its original 2600 hp Alco engines are also described [5]. Of late the concept of fuel cell locomotives and hybrid locomotives as a measure to conserve energy [6]. Hence the need to study the technologies in diesel locomotives become all the more important in way of improving its efficiency and reducing the losses by adoption of best technological features available. At the end the various technical advancements in the world of locomotive technology is discussed.

II. Internal Combustion Engines

Internal Combustion (IC) engines have wide application in today's world and we have engines in range from 0.1 kW to large marine installations of 80000 kW capacity. Accordingly today the engine rpm varies from 60-100 rpm for large capacity engines to 20,000 rpm for racing car engines. The power to weight ratio in kg/kW varies from 0.4 to 55 kg/kW for slow speed engines. Specific power output ranges from 3 kW/ltr to 100 kW/ltr in turbocharged SI engines used in racing cars. Thus IC engines have global application and accordingly railways too use IC engines as their prime movers. The huge diesel engines of few MW capacities are powering the electrical generators which feed to the traction motors for hauling the diesel-electric locomotives.

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III. Similarities Between Two Engine Technologies

The following are the similar features of both the locomotive engines. Both the engines run on diesel fuel and have 16 cylinders arranged in 45^{o} V section [7]. The engine is fabricated one with steel plates and the wet cylinder liners are inserted into the cylinder blocks. The fuel injection is direct into the cylinder and has one pump, fuel injector per cylinder. Basically of them have mechanical fuel injection but the EMD engine has integrated unit fuel injection. The turbo supercharger has an intercooler and delivers air at 1.5 to 2.2 bars. The cylinder liners are wet type and they have forged alloy crankshaft with nitrided bearings. Camshafts have replaceable sections with larger diameter lobes and the engines require prelubrication once they are stopped for 48 hours or more.

Table 1: Comparison of two locomotive technologies over Indian Railways

Feature	ALCO	GM (EMD)	Remarks
Model	251 B, C	GT 710	ALCO – 4 Stroke technology GT 710 – 2 stroke technology
Fuel Injector	Separate Fuel Pump and Injector	Combined Pump and Injector (Unit injection)	The high pressure hose connecting the pump to the injector is eliminated. Thus on line failures are reduced
Cylinder Capacity	668 cubic inches	710 cubic inches	Higher cc leads to higher power generation per cylinder
Bore and Stroke	Bore 9", Stroke 10.5"		
Compression Ratio (CR)	12:1, 12.5:1	16:1	Higher CR leads to higher thermal efficiency
Brake mean effective pressure	13-18 bar Continuous and 4-20 bar standby		
Turbo supercharger	Purely Exhaust driven	Initially mechanical drive from engine , later driven by exhaust gas at 538^{o}C	In EMD locos we do not find black smoke during initial cranking as the excess air is supplied by turbo for complete combustion of fuel.

Cylinder liners	Open grain chrome plated liners		Open grain liners ensure adequate oil film thickness yielding low wear rates and low lube oil consumption
Cylinder head	Steel Casing		Stronger casting keeps thermal distortion and mechanical deflection to minimum
Engine	4 stroke	2 stroke	4 stroke has better thermal efficiency as compared to 2 stroke. 2 stroke engines are easier to crank and start.
Piston	Super bowl		Better combustion, increased fuel efficiency
Valves	2 Valves for Inlet and 2 for Exhaust	Inlet ports and exhaust 4 valves	There are 2 valves for intake and 2 valves for exhaust in ALCO. In EMD locos 2 valves are for exhaust alone.
Valve operation	Push rod	Overhead cam shaft (OHC)	OHC eliminates long pushrods and hence the noise, friction and failures due to push rods are reduced.

Feature	**ALCO**	**GM (EMD)**	**Remarks**
Engine starting	Battery drives the auxiliary generator	2 DC motors with bendix drives which rotate the ring gear on flywheel	Easy to start as the two starter motors produce enough torque to crank the engine.
Radiator	Floor Mounted	Slanted and Roof mounted	Easy Maintenance. No coolant stored in Radiator Tubes when at rest.
Radiator bonding	Soldered	Mechanically bonded-Stronger	Mechanically bonded radiators are stronger than soldered ones and also give better reliability in service.
Specific fuel consumption	160 gm/kWh	156 gm/kWh	SFC are very close and in tune with technology in vogue.
Engine rpm maximum	1000	904	Higher rpm results in higher power output with other parameters being same.
Idle rpm	400	250	Low rpm results in low noise, reduced fuel consumption
Low idle feature	Not available	205 rpm when the notch is at Zero	Low idle feature ensures lean fuel consumption during idling.
Radiator Fan	Eddy Current Clutch 86 hp	AC motor	Less power consumption by auxiliaries
Maintenance	Every fortnight	Every three months	Higher maintenance periodicity ensures greater availability of loco for traffic use.
Cylinder Capacity		710 cubic Inches	
Scavenging	NA	Uniflow scavenging	Uniflow scavenging results in better scavenging when compared with conventional 2 stroke engines.
Power Pulse	Every 45^o	Every 22.5^o	EMD engines develop smooth power, torque and thus less vibrations

Feature	**ALCO**	**GM (EMD)**	**Remarks**
Engine Design		Narrow V type	
Crank Case Ventilation	Dc motor Blower	Eductor System, Mechanical Venturi	Eductor system employs venturi system and hence no power is consumed
Air box		Available with Positive pressure	The air pressure in air box is positive and above atmospheric pressure.
Crankshaft	One piece forged	Two piece drop forged joined by flange at centre (5 and 6 main bearing)	Crankshaft manufacturing cost and complexity is reduced by having 2 piece crank shaft.
Power Pack		Consists of Cylinder, Cylinder head, piston, carrier and CR	Allows dismounting and replacement of entire power pack.
Piston	Forged steel piston crown bolted to	Cast Iron alloy phosphate coated	

	aluminum alloy piston (Steel Cap)		
Piston Carrier	No	Piston free to rotate on the carrier	Piston rotation ensures uniform wear of piston rings and better life of piston.
Connecting Rod design		Interlocking to reduce length of engine Blade Rod and Fork Rod	Overall length of the engine is reduced by the design of fork and blade rod.
Cylinder Head rocker arm adjustment		Lash adjusters	Self adjusting lash adjusters
Camshafts	4 piece per bank	2 piece sectional per bank	Lighter and slender camshaft.
Fuel Injection pressure		1380- 2070 bar	
High pressure fuel lines	Auto frettage fuel lines	Not Applicable due to unit injection	Auto frettage fuel lines also cause engine failures due to engine vibrations.
Fuel pump	DC	AC pump 24 lpm	AC motor pumps are more reliable than DC pumps
Fuel filter		30 micron primary and 5 micron secondary spin on	Micro filtration reduces ingress of foreign matter and prolongs the life of cylinder and pistons.

IV. Conclusion

Locomotive technologies are evolving over the years. Both these technologies i.e. two stroke technology and four stroke technology have their comparative merits and demerits. The various sub assemblies, components and manufacturing technologies have been enumerated. The comparative study of these two technologies shall help the railway engineers to understand their locomotives and plan for maintenance in a better way. Engineering students studying in numerous engineering colleges do not have access to these locomotives technologies and are deprived of a suitable document comparing these technologies. This paper allows the students to understand comprehensively the locomotive engine technologies in a better manner.

From the data provided above it is seen that IR has changed with changing times and introduced new technologies. But still there are areas which IR has to look into and accordingly IR has taken up research in those areas. The following are few areas for improvement in diesel engine technologies

1. Electronic fuel injection [8]
2. Variable valve timing
3. Waste heat recovery from exhaust gases leaving the turbo super charger
4. Higher injection pressures like Common rail direct injection

Lately IR has upgraded the EMD locomotive engine from 4000 to 4500 hp by adopting the following features.

1. Engine rpm increased from 904 to 950.
2. Fuel delivery increased
3. Turbo speed maintained at upper limit of 21,500 rpm
4. Over speed trip assembly adjusted to incorporate enhanced rpm
5. Preventing undue vibrations of the engine.

In days to come due to advancement in technology the conventional traction systems shall be replaced with fuel cells operating on hydrogen [9]. Even in the recent past China has witnessed lower emission intensity due to electrification of its tracks and we can expect that this trend shall continue [10]. Recently Government of India has entered into understanding with General Electric to manufacture 4500-6000 hp diesel locomotives for Indian Railways. This indicates that diesel technologies shall continue for few more decades to come in India.

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