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Darjeeling Himalayan Railways - Steam Locomotives And Their Problems

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Abstract: The narrow gauge steam locomotives of the Darjeeling Himalayan Railways are the existing examples of the external combustion engines, which played a key role for transportation in the region before the advent of the automobiles. However, their condition today is grim. In this paper we present the various technical shortcomings and suggestions for improvement of the Class B narrow gauge steam locomotives.

Keywords: Condenser, Fire Tube Boiler, Flue Gas Analysis, Saturated Steam, Super heater

1. Introduction

For sustenance both commercially and environmentally, Energy Conservation is one of the prime topic that we need to focus upon. The rising price of the liquid fuel globally is already an indication that these are scanty and the need of the time is for the search of alternatives. Also, Indian Economy is largely dominated by oil imports; and it is definitely affected by these periodic escalating prices of the liquid fuel. However, India is well endowed with ample of coal reserves which may last for the next 150 years [1]. The coal fired steam locomotives of the Darjeeling Himalayan Railways which were there since 1881, played a big role in transportation during the British era and before the advent of the automotives. First Narrow Gauge trains became operational in the Darjeeling Hills as early as the July of 1881. However their conditions today have become grim even after their inclusion as a World Heritage Site, not only because these locomotives have become old with very less research and development in them, but also the region and their tracts often faces huge landslides. In this paper we present the various technical shortcomings and suggestions for improvement of these Class B narrow gauge steam locomotives. In section 2, we discuss the general aspect of the class B type of Steam locomotives present in the Darjeeling Himalayan Railways, in section 3 we present the various technical shortcomings of these old locos and in section 4 we present the scope for their improvements.

2. The Steam Locomotive

The steam locomotives of DHR are of Class B types and are an existing example of external combustion engines. It hosts a fire tube boiler with 61 fire tubes with a length of 3.035 m (each), outer diameter 4.2 cm, and a total heating surface of 29.40 m^2 and generates steam at a pressure of 140 psi (pounds per square inch) i.e. 9.54 kg/ cm^2 (figure 1). Saturated steam is sent to the cylinders (pistons) containing D-slide valve located on both side of the engine from the throttle valve located on the dome above the boiler, when the boiler pressure reaches 140 psi [2]. However due to en route condensation of the saturated steam as there is no superheating of the steam, the mean effective pressure (MEP) is much lesser. The cylinders are two in numbers, each with diameter 27.94 cm and produces a tractive force of 34.74 kN at a MEP of 85%, as the steam not being superheated a part of it condenses before it reaches the cylinders and thus the pressure decreases. The expanded saturated steam at atmospheric pressure exhausted from the cylinders exits the locomotive through the blast pipe in the smoke box situated at the front as the locomotive does not host any condenser or steam recovery system, and in this process, causes an induced draught as well as the nostalgic "chug chug" sound of the locomotive. Pre crushed coal to a size of 3 – 5 cms is fed manually in the firebox which hosts a fire grate with an area 0.81 m^2. Ash is collected at the ash pan, situated just below the fire grate through which the combustion air is also taken in. Water is carried on the saddle tank which has a capacity of 1818.36 litres and transferred to the bottom tank before fed into the boiler through an injector which increases the pressure to about 10% higher than the boiler pressure, whenever the level of water inside the boiler drops which is indicated by a pair of watch glass situated where the locomotive driver stands. Unlike stationary boilers, feed water is not treated and **is** fed at different locations along the route.

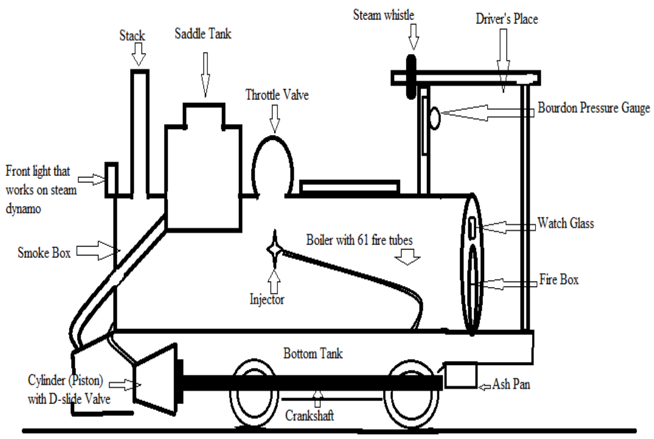

Figure 1: *Schematic diagram of the Class – B Narrow Gauge Locomotive of DHR*

3. The Problem

Several factors contribute to the low mean effective pressure (MEP) of the steam that reaches the cylinders to be converted into useful tractive force. These include the losses from auxiliary utilities like steam whistle, bourdon pressure gauge, blow down and radiation losses apart from the major losses discussed below.

3.1 Lower Boiler Efficiency

A flue gas analysis was done from the sample of smoke collected from DHR's locomotive number 791 at the Kurseong Loco Shed on 26th October 2008 (Table 1). In addition, proximate analysis of the coal used was done and combustible in refuse was also determined. An indirect method (calculation of losses) to determine the boiler efficiency was done [2]. A boiler efficiency value of 60.4 % was determined. The low boiler efficiency is a result of the following losses [2].

Table 1: *Orsat Flue Gas Analysis of the Sample of Smoke collected from the DHR Locomotive 791 at Kurseong Loco shed on 26/ 10/ 2008*

Sl No.	Description	Amount
1	Air Temperature, T_i (Dry Bulb Temperature)	16.5˚ C
2	Wet Bulb Temperature (WBT)	15˚ C
3	Flue Gas Temperature, T_o	175˚ C
4	Carbon dioxide (CO_2)	17 %
5	Oxygen (O_2)	2.4 %
6	Carbon Monoxide (CO)	0.9 %
7	Nitrogen (N_2)	79.7 %

3.2 High Loss in Combustibles

The loss of combustibles, that is in fly ash and the ash content was found to be high which may be due to various reason like improper bed thickness, inadequate bed area, improper coal preparation, lower temperature in the combustion zone, improper air pressure and low residence time of the flue gas, i.e. due to inadequate length of the boiler tubes [3].

3.3 High Excess Air

Some amount of excess air is always required for combustion of fuel. However, high excess air has the following adverse impacts (i) Lowers combustion zone (furnace) temperature – the cold atmospheric air in excess cools down the furnace leading to lower furnace temperature; (ii) Reduces residence time – higher the volume of gases, higher is the gas velocity, thus the residence time of the flue gas decreases which reduces the heat transfer rate; and (iii) lowers radiation heat transfer in the furnace - as the furnace temperature lowers due to cooling of furnace as illustrated in (i) the radiation heat transfer from the furnace area reduces, thereby reducing steam generation capacity [4].

3.4 Scaling of Boiler Tubes

Significant scaling on the water side and soot on the water side of the fire tubes were noticed. The average thickness of the scale was found to be 1.5 mm, which considerably reduces the heat transfer rate [2]. The scale formation is basically due to the ion content in the untreated water used in these boilers.

3.5 Other causes

Apart from the combustion losses from the boiler, there are other factors which cause the degradation in performance of the steam locomotive.

3.5.1 Absence of Super heater

In case of steam locos, the superheating is done inside the smoke box with the further (more complete) combustion of the flue gas. However, superheating is not done in the steam locos of DHR owing to its small size.

3.5.2 Absence of Condensers

Loss of saturated vapour at atmospheric pressure which still contains the enthalpy of vaporization is perhaps the most significant loss in any external combustion engines without condensers.

3.5.3 No Preheating of Combustion air

The steam locos are too small to host any pre heaters. In actual case, the combustion air along with the excess air (more than the theoretical requirement for complete combustion) contains 3.76 moles of other gases chiefly nitrogen which does not take part in combustion process but simply is an extra baggage when the combustion air enters and leaves as flue gas. However, they too are heated from the atmospheric inlet temperature to the high flue gas temperature gulping a significant amount of thermal energy.

4. Scope for Improvement

The boundary work done by expanding high pressure steam is used to overcome friction between the piston and the cylinder, to push atmospheric air out of the way and to move the crankshaft [5].

$$W_b = W_{friction} + W_{atm} + W_{crank} = \int [F_{friction} + P_{atm}A + F_{crank}]dx \quad (1)$$

Work done at the crankshaft, W_{crank} is the useful work and in order to increase this useful work, either W_b should be increased, which implies the more use of steam and hence more powerful boilers and higher firing rates, which may not be feasible in small moving boilers as in the cases of DHR's NG locomotives. However, the other components on the right hand side of the above equation ($W_{friction} + W_{atm}$) tell us about the management of the existing system and the efficient use of the high pressure steam. $W_{friction}$, is the work done in overcoming the friction between the piston and the cylinder and can be reduced by properly maintaining the cylinder and with better lubrication to attain a frictionless smooth surface. W_{atm}, is the work done in pushing the atmospheric air while expanding and can be significantly reduced if the pressure term on the right hand side of the equation (i.e. $P_{atm}A$) is reduced. However, for this to be achieved, the exhaust steam from the cylinder need to be condensed, i.e. the use of condensers.

4.1 Use of Condensers

The major cause of low efficiency in a steam locomotive is the exhaust of saturated vapour (at atmospheric pressure) from the cylinder, which still contains enthalpy of vaporisation (2020.84 kJ/ kg). This unrecovered heat is permanently lost into the atmosphere. Use of condensers to condense the exhaust steam will cause a partial vacuum in the blast pipe (exhaust pipe), thus more work can be extracted from the cylinder [6]. Steam locomotives that use condensers have periodically appeared on railway during the heyday of steam operation. The most notable examples were the Class – 25C’s used on the South Africa Railways during the post WW2 years, to extend their operating range of steam locomotives across the arid Great Karroo region, located on the western side of South Africa. The other benefits are the fact that the condensed water which is at a higher temperature, can be reused or fed into the boiler, thus decreasing the requirement of thermal energy and coal in order to increase the temperature of the feed water. At 140 psi or about 1 MPA, the enthalpy of vaporization of water = 2020 kJ/kg = 482.7 kcal/kg. As per data given by the railway officials, for a distance of 97 kms from Siliguri to Darjeeling, at present the locomotive consumes about 2000 kgs of coal. Thus in a one way journey, (482.7 x 2000)/ GCV_{coal} ~ 240 kgs of coal is saved, which is equivalent to 88 tonnes of coal per year and 323 tonnes of CO_2 every year [2]. However, the major obstacle is the relatively small size of the locomotives of the DHR region than those of other areas, and which cannot be increased much due to sharp cures in the tracts as much as 132˚ R. In fact, these locos are so small, that the feed water has to be refilled at several places as the tender is not sufficient. Also, the fouling by the lubrication oils used in the cylinders needs to be attended first if a condenser is employed in the system.

4.2 Use of Super Heaters

Super heaters heat the steam above the saturation temperature for the given pressure, as a result the steam does not get condensed en route to the cylinders, in other words the dryness factor increase and the mean effective pressure of the steam that reaches the cylinders is higher. At 140 psi (1 MPA) the saturation temperature of water is 179˚ C and specific volume (V_1) 0.19437 m^3/ kg. Under average conditions, the steam consumption of an engine using saturated steam reduces by 1% for every 10 degrees of superheating if superheated steam is used [4]. Superheating of steam in case of locomotives is usually done in the smoke box by a more complete combustion/ utilization of the flue gas that comes out of the boiler tubes.

4.3 Substitution of Steam Whistle and Steam Dynamo

The locomotives of DHR derive all the power from the high pressure steam, i.e., even the whistle and the dynamo for lighting. Though it may affect the heritage aspect of these locomotives, the steam whistle and steam dynamo if replaced by a horn and a battery dynamo, would reduce the load on the boilers.

4.4 Inclusion of Renewable Resources

Research in the field of utilization of biomass based fuels like briquette, in addition to traditional coal based firing system or even a combination of the two, may not only bring down the consumption of coal, but also decrease the CO_2 emission. However, the existing boiler system need to be properly studied and features like the bed width, thickness, draught, firing rates, air supply etc need to be properly modified to accommodate the changed combustion pattern.

4.5 Research and Modernization

Steam locomotive modernization is the application of principles fully adopted in advanced locomotive design to existing old engines, without involving structural changes, and for the purpose of improving their performance. Some of the areas, where the steam locomotives can be studied and modified to increase their performance are the improved boiler insulation, use of economizer, general mechanical improvements, light weight reciprocating parts, substitution of uneconomical turbo generator, advanced feed water treatment eliminating corrosion, scale, caustic embrittlement, one man operation, Poissonnier repair method, new cylinders of advanced design, three cylinder compounding (if space permits), anti-slipping devices, etc.

4.6 Others

The high pressure steam generated by the boilers must be used in the most frugal manner. The leakage of the steam from the throttle valve, injectors, and auxiliary devices like the bourdon pressure gauge should be minimized to increase the mean effective pressure (MEP) of the locomotive.

5. Conclusion

Though the Loco Workshop at Tindharia which was established on 1925, engages itself in Periodic Overhauling of the steam locomotives, narrow gauge coaches, special repairs and manufacturing of components for the locomotive and coach, sufficient know how as well as training amongst staff and investment in steam technology by the government has crippled. Also, the already small locomotives with lower steam generating capacity due to shorter tube length are yoked by heavier coaches these days. All these factors have led to the decrease in the pulling power.

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