भारत सरकार Government Of India
रेल मंत्रालय Ministry Of Railways
(रेलवे बोर्ड) (Railway Board)

Minutes Of The 1st Meeting Of
Sub Committee of Advisory Group of Experts (AGE)
on
"Turbine Based Power Plant"
Held at RDSO on Thursday, 23rd February, 2017

1. In terms of Railway Board's letter no. 2015/CE-I/Innov./6, dated 18.02.17; meeting of the Sub-Committee on 'Turbine Based Power Plant' was held on 23.02.2017 at RDSO, Lucknow.

2. Following officials were present :

i.	Dr. N K Gupta	*Member-'AGE' & Chairman, Sub-Committee on 'Turbine Based Power Plant' and Ex. Project Director/ISRO*
ii.	Shri Alok Kumar	*Convener Member–'AGE' & Sub-Committee on 'Turbine Based Power Plant' and Chief Engineer/HQ/NR*
iii.	Shri Ravinder Gupta	*CAO/IROAF*
iv.	Shri Satish Kumar	*CPLE/DMW*
v.	Shri A.K. Singh	*CDE/DLW*
vi.	Dr. Anirudh Gautam	*GGM/RSD/RITES*
vii.	Shri V.K. Agarwal	*ED/Research/RDSO*
viii.	Shri R.K.M. Pasi	*ED/ED/RDSO*
ix.	Shri Abhijeet Singh	*Director/MP/RDSO*
x.	Shri Vineet Singhal	*Director/ED/RDSO*
xi.	Shri Amit Srivastava	*Director/Research (Mechanical)/RDSO*
xii.	Shri T.K. Khare	*Director/Research (S&T) /RDSO*
xiii.	Shri Anurag Mishra	*Jt.Director/MP/RDSO*
xiv.	Shri K.B. Raja	*Add.GM/BHEL/Hyderabad*
xv.	Shri Rajulin Dhas	*Dy. Manager /NTPC*
xvi.	Shri Parthsarthi Hans	*Scientist F/GTRE/ Bengaluru*
xvii.	Shri Amit Kumar	*Scientist E/GTRE/Bengaluru*
xviii.	Shri Nagaraja Betageri	*Scientist E/GTRE/ Bengaluru*

3. Meeting started with welcome note by ED/Research/RDSO for the participants.

4. **Discussions on the opening presentation "Gas Turbine Locomotive for Indian Railways" given by Dr. Anirudh Gautam of RITES**

(i) This presentation covered the reserves of LNG in INDIA and development of 8.3 MW NGTL by Russian Railways and similar efforts by Indian Railways.

(ii) Previously IR have done MoU with IOC for LNG supply which has since expired, but similar MoU can be done with M/s PETRONET, who have shown willingness. It was informed by BHEL that Indian gas companies are entering into long term purchase

agreement for LNG, which is expected to bring down the costs substantially. Use of natural gas is beneficial to India, both economically and environmentally.

(iii) Earlier a draft MoU between RDSO, RITES, Indian NAVY, BHEL and GTRE was formed. Similar effort will be required for development of gas turbine locomotive as the need for Collaborative research is required similar to the path followed by Russians.

(iv) Russians have designed their 8.3 MW gas turbine locomotive with a twin vehicle concept with Bo-Bo-Bo bogie design.

(v) CAO/IROAF may put emphasis on the need of keeping maintenance expenses also in mind while moving away from Diesel Locomotive .The newly adopted prime mover should be cost effective and easily maintainable.

(vi) Micro Turbines provide another alternate to solve the problem of part load operation on locomotives and for a wide power range duty cycle for commuter trains. Air bearing sealed turbine–generators are available in 200/300 kW unit which can be combined together or with larger turbine sets at DC output level to provide better flexibility in output. Micro turbines can also be used as a cluster for commuter train DPCs.

(vii) NTPC suggested that while assessing the techno economic feasibility of the Gas Turbine locomotive, a comparison is also to be made vis a vis electric locomotive. NTPC shared from their experience that the electricity generated from LNG is commercially less competitive and they find it difficult to market electricity produced from natural gas turbine. NTPC informed that the current price of LNG is about USD 12-13 per MMBTU for their gas based power plants. This is expected to reduce to USD 8-9 per MMBTU for the long term LNG contracts signed by India.

(viii) CPLE/DMW mentioned that group should take into account the following in regard to development of LNG Loco which is useful for Gas Turbine loco development :-

- LNG Loco development at DMW, Patiala, could not go ahead due to requirement of tender for LNG storage. The requirement of additional one loco length for LNG storage was not agreeable to traffic department, as this was considered loss of effective train length for commercial purpose.
- The offer of Rs. 46.3 crore (from M/s Westport) for LNG loco was considered very high as against sanctioned cost of Rs. 22.3 crore. In current case of GT loco also, the sanction is of only Rs. 19.3 crore (*item no. 194 of Pink book 17-18*). As gathered from the discussion during the meeting, the expected cost would be around Rs. 70-80 crore. Group should deliberate this issue in next meeting.
- Issue of LNG to gas conversion, which will also be applicable for GT loco, need to be addressed as it is understood that development of LNG loco at EMD from their engine test bed to road is pending on account of development of cryogenic pump. In addition, international standard for safety of LNG storage module & crashworthiness for railroad application needs to be deliberated.
- Emission standards which are targeted, needs to be discussed and what will be achievable for GT Loco should be known in advance.
- The current electricity price for Indian Railways is around Rs. 4 to 7 per unit. Therefore, it has to be seen whether the gas turbine locomotive running cost will be able to match the electric locomotive running cost.

(ix) Dr. Anirudh Gautam explained that the use of twin vehicle concept was proposed by RDSO after detailed discussions with Traffic Directorate of Railway Board as well as

calculations to prove that there is no loss of one wagon/coach due to use of additional vehicle for carrying fuel even on loop lengths. Also, the 12000 hp electric locomotive is already planned to be manufactured with twin vehicle concept.

(x) Furthermore, LNG tank on the same vehicle as the engine is not possible due to lesser density of LNG as compared to diesel and cannot be mounted underneath the under frame due to requirements of venting.

(xi) Dr. Anirudh Gautam informed that BHEL has given a cost of Rs. 46 Crore for development of the gas turbine locomotive, where the total charges including project management charges, taxes, duties, separate vehicle cost etc. came out to be Rs. 72 crore. Vis-à-vis this budgetary quotation by BHEL the Russian Railways had indicated a cost of Rs. 40-45 crore for the complete development of the gas turbine locomotive. These costs were rechecked from market and the following break-up was obtained :

- 8-9 MW gas turbine state-of-the-art technology from M/s CAT Solar gas turbines – Rs. 25 crore
- Electrics and additional vehicle cost and the tanks, accessories etc. – Rs. 10-12 crore
- Development cost Rs. 5-8 crore
- TOTAL – approximately Rs. 45 crore for a 12000 hp gas turbine locomotive. This calculates to Rs. 37,500 per hp for a prototype gas turbine locomotive which will reduce with series manufacture.
- At present the cost of a 6000 hp electric locomotive is about Rs. 17 crore. So, for two locomotives comes to Rs.34 crore without including the proportioned cost of the electricity generation and distribution which comes to Rs. 28,333 per hp for series locomotives.
- Therefore, the cost of series gas turbine locomotives will be around the same as two electric locomotives minus the electricity generation and T&D costs.
- For the GT locomotive, the issue of cryogenic pump development at high pressure will not be an issue since the LNG is pumped at close to atmospheric pressure. Technology and cryogenic pumps for this application are commercially available.
- CAO/IROAF also mentioned that gas turbine engines are fuel independent, i.e. other alternative fuels like methanol can also be used in the same engine without any modifications. This point was accepted by BHEL and NTPC.

(xii) It was agreed that we have to consider the well to wheel costs of operation and not only the tank to wheel costs. The tank to wheel cost of operation of the gas turbine locomotive will be free of the T&D losses, transmission line and overhead lines maintenance costs whereas the efficiencies of the turbines will be in similar range. This will provide advantage to the gas turbine locomotive. Well to wheel costs cover the complete life cycle cost of fuel beginning from the well from where the petroleum is extracted to the tank of the vehicle and thence in the vehicle to its wheel.

(xiii) ED/Research /RDSO brought out that strategically we need alternate power plant even after 100 % electrification giving the example of South Eastern Railway which is fully electrified and operates about 40% diesel locomotives under wire.

(xiv) It was agreed to include a comparison of gas turbine based locomotive vs. electric locomotive in the DPR considering all the above aspects.

5. Discussions on "Probable Use of Kaveri Engine in Locomotive" presented by Shri Nagaraja Betageri of GTRE –

(i) GTRE informed that KAVERI engine for TEJAS and its marine derivative, i.e. Kaveri Marine Gas Turbine (KMGT) are not usable in the present form on a locomotive as this will require major modifications to the engine and will take a long time of about 8 years. This is basically due to the difference in target applications as Kaveri and KMGT were designed for Defence application, where performance is primary and cost is of secondary importance; while in locomotive application, an optimum solution between cost effective and efficient turbine engine is the requirement.

(ii) GTRE brought out the technological challenges for using existing KMGT engine in the locomotive is basically cost of materials since, being an aero derivative engine, KMGT utilizes exotic materials such as Titanium, Nickel, Cobalt based alloys, which are expensive.

(iii) Total weight of the a KMGT engine is around 2 tons which produces around 12 MW power at 35°C ambient temperature. Production cost of a KMGT is around Rs.30 crore. Therefore, deciding material is one of the first major challenges for designing a gas turbine for locomotive applications.

(iv) Designing of combustor, fuel storage and handling system, control logics and associated systems, will require a redesign of KMGT to make it suitable for locomotive applications. This is a time consuming process.

(v) Fitment of KMGT engine on the Locomotive platform is required to be examined, as the KMGT engine including its mounting system has a width of 2.1 metres.

(vi) GTRE informed that Kaveri Marine Gas Turbine was tested in Naval Dock Yard for demonstrating its performance on a dynamometer. RPM of this turbine is around 5000-6000 rpm and shaft power was around 12 MW. After de-rating the KMGT to produce 6 MW power, as required by Indian Railways, efficiency of the de-rated engine will be 22.7%.

(vii) GTRE informed that a Japanese consortium led by Kawasaki Heavy Industries is developing a Super Marine Gas turbine to produce 2.5 MW power with a high thermal efficiency of 39%.

(viii) GTRE raised the issue of Gas turbine being very sensitive to the ambient temperature. Hence, its efficiency is also largely dependent on this parameter. Normally high ambient air temperature will tend to decrease the thermal efficiency of the gas turbine.

(ix) GTRE also mentioned that Russian Railways might have adopted Gas Turbine Loco to exploit abundant gas reserves and low temperatures in Siberia area, which gives rise to higher efficiency. But, it has not been proliferated in other parts of Russia or the World which are hotter.

(x) Dr. Gautam brought out that gas turbine locomotives have been developed by different countries in different geographical locations because of their inherent advantages over other prime movers. Russian Railways have since given order for manufacture of another 40 GT locomotives for their fleet not necessarily to run in very cold climates. Also, the trucks developed with LNG fuel tanks by Westport and Cummins run in Australia in very hot climates. Furthermore, Union Pacific, Florida East Coast railway in USA is running experimental LNG fuelled trains across the length and breadth of USA in varying temperatures. IROAF is also planning to build DEMUs with LNG as fuel for its suburban operations due to larger energy carrying capacity and higher safety.

(xi) ED/Research also raised the issue of adequacy of the present couplers and train length to handle the increased horsepower of gas turbine locomotives. He suggested that two gas turbine locomotives with distributed power can also be tried out.

(xii) Hot Exhaust gas from gas turbine engines would be required to be taken care of, as air mass flow of a gas turbine engine is higher than a diesel engine.

(xiii) Concept of free power turbines for use in locomotive application was also discussed. Turbine has to fulfill the variable speed engines power requirement for a locomotive application. Noise issues are also important factors as the locomotive will pass through urban and densely populated areas.

(xiv) Turbine engine noise testing, development of combustion test facilities and testing facilities for shaft power would be required to be established by Railways/BHEL as currently there is no testing facility available in India.

(xv) Different phases in the turbine design are engine & module design, detailed design, prototype manufacture; testing and certification and it takes around 84 months minimum (7 years). Therefore development time for a new turbine will be around 8-10 years and overall it is an investment intensive program.

6. Discussions on "LNG fueled Gas Turbine Locomotive presented by Shri K B Raja, BHEL –

(i) BHEL is manufacturing Heavy duty Industrial Gas Turbines under a licensing agreement with M/s General Electric USA since 1988. The Power ratings of the GTs currently manufactured range from 25MW to 300 MW. (BHEL has earlier manufactured few 4MW and 8MW units also)

(ii) BHEL is also planning to manufacture two variants (7MW and 16MW ratings) of marine gas turbines for the Indian Navy shortly through another licensing agreement from an overseas OEM. The ToT will be comprehensive and will include manufacturing rights for the complete GT.

(iii) BHEL is also in discussion with a European OEM for a ToT agreement for manufacture of a 1.8 MW Gas Turbine at BHEL. This GT is a rugged design with a radial compressor and turbine with best in class efficiency and TBO suitable for mobile application.

(iv) BHEL indicated that gas turbines due to their inherent exhibit drop in efficiencies on part load operations, and would be better suited for application in high powered locomotives, used on long distance operations with minimum stops.

(v) Increased availability of LNG in the future will enable increased use of LNG in the transport segment. Use of LNG will reduce operational cost and exhaust emissions.

(vi) Exhaust emissions like NOx and THC emissions from Gas turbines in locomotive applications has to be compared with these emissions from diesel locomotives of Indian Railways. Dr. Anirudh Gautam brought out that the NOx, PM and THC emissions have been compared for the two technologies by Russian Railways and there are significant reductions observed in the above specific emissions from gas turbine locomotive.

(vii) Different measures for improving gas turbine efficiency like recuperator; regeneration cycle etc. was also discussed. It was brought out that the thermal efficiency of the gas turbines can be significantly enhanced by use of above measures. The micro-turbine gas turbines of Capstone USA have used these technologies with increase in thermal

efficiencies. Similar technologies can be implemented on larger gas turbines to be used for locomotive mainline operation.

(viii) Currently there is no proven GT with a recuperative cycle in the 8MW range. Additionally, viability of configuring any means of using the exhaust waste heat for improving the efficiency on a moving platform will need to be studied.

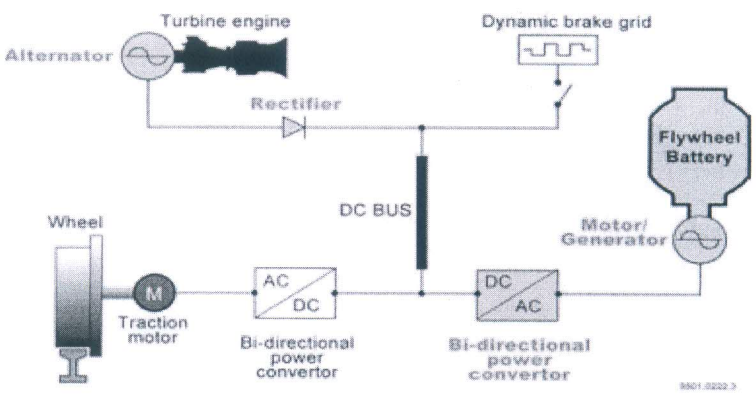
(ix) It was also emphasized that the selection (rating) of the gas turbine for the locomotive application needs to be factored to the duty cycle envisaged. The power requirement steeply increases with increase in speed and the duty cycle envisages long duration operations at lower speeds. Hence, the specifications may need to be fine tuned to optimize the application.

(x) It was also suggested that a hybrid system i.e. a combination of GT and diesel engine power plants could provide for an efficient system. The GT could be sized to provide base power (about 5-6 MW) operating on LNG while the diesel engine could be used intermittently for supporting higher speeds.

(xi) It was indicated that OEMs like Solar, Siemens, Zorya etc. have gas turbine models in the required range for the locomotive application.

(xii) It was also suggested that use of an energy storage device like fuel cells, batteries, flywheels, hydraulic devices etc. could also help in optimizing the application.

(xiii) The impact of Locomotive duty cycle has to be clearly mentioned in the DPR and specifications as turbine performance is largely dependent on this. Dr. Anirudh Gautam brought to the attention of the Committee the Advanced Locomotive Propulsion system (ALPS) which was developed at University of Texas, Austin, USA. The objective of the ALPS was to operate a hybrid propulsion system consisting of gas turbine prime mover, energy storage flywheel and high speed alternator in railroad environment. The ultimate goal of the project was to develop a gas turbine based locomotive capable of sustained speeds of 240 kmph with accelerations comparable to an electric locomotive, improved reliability and efficiency and reduced exhaust emissions. Initial simulations of turbine powered locomotives on high speed rail corridors indicated that thermal cycling due to variable power demands can be overcome by use of energy flywheel coupled to the gas turbine. Power flow schematic of the above arrangement is shown in figure below –



Power Flow Schematic

(xiv) For developing above configuration, Indian Railways can consider a MoU with University of Texas, Austin, USA and carry out system optimization to meet Indian

Railways requirement. With the above configuration, it will be possible to meet varying duty cycle power requirements of Indian Railways.

(xv) It was suggested during the meeting to contact Russian Railways for latest update on their development of Gas turbine locomotives. For this purpose, a question bank has to be prepared for Russian Railways.

7. Discussions on "VIEWS ON LOCO POWER" presented by Shri A.K. Singh, CDE/DLW, Varanasi –

(i) In this presentation space availability and weight calculations on a WDG4D locomotive were discussed. It was informed that 6000 litres diesel fuel tank provides a head for 800 - 1000 km.

(ii) It was brought out that the envelop size of KAVERI turbine engine needs to be studied and based on that, the Kaveri engine may be required to be modified to suit locomotive applications.

(iii) It was informed that an approx envelope size of 14.2 metre in length, 3.1 metre in width and 2.5 metre in height is available on board in WDG4D loco and an additional space of 7.5 metre (Length) x1.5 metre (Width) x 0.6 metre (Height) can also be used below top surface of under frame.

(iv) Further, since rear Cab is not required, an additional space of 2 metre in length above under frame will also be available.

(v) DLW informed that after removing diesel engine alongwith engine support system, approx 32 tons weight will be removed for application of turbine engine and weight of remaining part of loco will be 98 tons approx.

(vi) DLW also presented Duty cycle of WDG4 loco, which shows max. working on lower notches on normal routes. Thus, a study is required on efficiency of Kaveri engine/ turbine engine running on partial load.

(vii) DLW informed that loco redesigning work can be jointly taken up at DLW and RDSO.

8. <u>Decisions Taken In The Meeting</u> –

(i) The Group should develop two functional Schedule of Technical Requirements (STR) as the first step and look for available options without considering fresh development of a tailor made turbine for railway locomotives.

(ii) First specification is for a single gas turbine Locomotive of about 8 to 9 MW with LNG as fuel for long haul and heavy haul application and second specification for 1400 HP (1 to 1.2 MW) micro turbine based DPC with LNG as fuel.

(iii) The need for use of a suitable energy storage system or an auxiliary engine for the locomotive for operation on gradients and on part loads may also be considered while framing STR.

(iv) There is no need to develop a shunting locomotive. Instead, a Driving Power Car of about 1 to 1.2 MW may be developed based on turbine engine for substituting use of diesel on commuter train-sets with more economical & renewable alternate fuels.

(v) A DPR will be prepared keeping in view all the technical aspects like applicability in operation etc.

(vi) To contact Russian Railways for latest update on their development of Gas turbine locomotive. Question bank has to be prepared for Russian Railways.

(vii) ED(ED)/CNG/RDSO and EDS(MP)/RDSO have been co-opted as members of the Sub-Committee with the permission of the Chair.

(viii) Next meeting of the Committee shall be held at BHEL Hyderabad. Dates will be decided by the Chairman of Sub Committee.

(No. 2015/CE-I/Innov./6, New Delhi, Dated 31.03.2017)

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Distribution for information and necessary action :

1. The Chairman and all the Members of the Advisory Group of Experts.
2. The Chairman and all the Members of the Sub-Committee on 'Turbine Based Power Plant'.
3. The General Managers, All Zonal Railways.
4. Directors General – RDSO/Lucknow and NAIR/Vadodara.

Copy to :

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- General Manager and Pr.CE, Northern Railway, New Delhi
- ED(ED)/CNG/RDSO and EDS(MP)/RDSO for information and necessary action.