RECORD OF NOTES – TESTING OF X4V2 REVETEC ENGINE AT PEUS TESTING GMBH, OTTENAU, GERMANY

Date	29th June, 2011 to 7th July, 2011
Venue	Peus Testing GMbH,Z Ottenau, Germany

Revetec India Technologies Pvt Ltd (Group company of Revetec Holdings Ltd, Australia)	**Ashok Leyland Ltd, India**
o Bradley Howell Smith, Director Technical	o Ramesh Santhanam, Head Projects
o Steven Valtas, Managing Director	o D. Chakraborty, Head, Appln Engg, Engines
o Michael Howell Smith	o Sunil Kumar Pandey (Engine R&D)
o Robert Pach (Peus)	
o Martin Hess (Peus)	
o Markus	

1) BACKGROUND OF TECHNOLOGY HOLDER

a) Revetec Technologies India Private Limited (RTI) has recently been incorporated in India; Indian entity holds the Global Master Licence of all CCE and other technologies, patents and know-how (past, present and future included) of Revetec Holdings Ltd, Australia (RHA) on an exclusive basis.

b) RTI, incorporated by Revetec Holdings Limited has at the request of Ashok Leyland Ltd (AL) arranged for the validation testing of its fundamental concept crankshaft less trilobate technology at the facilities of Peus Testing (a Group company of AVL Germany);

2) EXECUTIVE SNAPSHOT

a) A limited trial was conducted in Peus Testing on a 68 kW Revetec X2V4 gasoline engine. (The testing period was limited due to some limitations imposed by the test bed and component failure). The testing included dismantling of the engine and a fairly detailed study of its various mechanisms.

i) Preliminary investigation of the limited data collated and study of the dismantled engine and its operational characteristics at the component level revealed the following:

(1) The fundamental concept that trilobate can replace crankshaft was evident;

(2) Basic engine performance from the point of view of lower fuel consumption and flatter torque were noticed to a reasonable extent.

(3) On closer observation of the mechanism / internals, combustion taking place closer to the TDC providing better fuel efficiency was evident; a 10% improvement on BSFC was seen; a 12 to 20% better fuel efficiency seems very promising for diesel engines as well.

(4) The engine design is relatively simple and manufacturable.

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(5) **The design of the engine being radically different, the performance at various loads / speeds is very different from conventional IC engines; this mandates that the engine be tested for atleast 250 to 500 hours which would facilitate a more detailed understanding of its performance and emission characteristics and for ensuring sustained performance;**

(6) The size of the bearing and profile of the trilobate play which dictate the acceleration rate of the piston / combustion is a major factor that seems to dictate the performance of the engine – this area requires a much more detailed analysis to achieve optimization for a given set of applications

(7) The mechanical advantage provided by the trilobate design seems to provide ample scope for improving AL engines.

(8) It is recommended that the X4V2 engine be further tested in AL Hosur / Ennore test bed to better understand the engine performance characteristic while taking up simultaneously the Diesel development program in a phased manner.

3) TESTING OBJECTIVE

a) Revetec's Bottom End Mechanical Advantage System consists of rotating trilobate cams instead of a crankshaft; a testing was organized by RTI to validate the following:

i) Trilobate cams can replace crankshaft and produce power efficiently,

ii) Basic concept is mechanically more efficient than a conventional crankshaft and as a result can provide potential fuel savings in the range of 10 to 20% approximately over and above that is provided by current conventional combustion engines,

iii) To establish whether the engine is capable of a reasonable flat torque and whether there is a noticeable and meaningful improvement in fuel consumption for a given power (which will facilitate a decision to consider moving from crankshaft to trilobate design).

iv) To verify that the bottom-en mechanical system provides the prospect of a serious reduction in overall engine weight for a given power output.

b) TESTING PROTOCOL / OTHER REQUIREMENTS

i) FREE RUNNING PHASE – AL requested Revetec to show that that the engine can really run without a crankshaft and produce power and the fundamental design-concept is basically sound / workable;

ii) ANALYSIS – TECHNOLOGY – AL had requested Revetec for a complete rundown of the engine from the first stage of development till date

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including analysis of past and present data from Orbital Australia Pty Ltd and Peus Testing;

iii) DURABILITY - Revetec was asked to strip the critical engine parts post testing phase for any obvious wear and tear patterns and for study of its internals to have a first level of understanding of its operational characteristics.

iv) DETAILED TEST BED ANALYSIS - AL requested Revetec that the engine be run on the test bed and the performance and emission (Refer to attached data) be recorded for 25%, 50%, 75% and 85&% load (including for no-load) for 1200, 1500, 1800, 2200 and 2500 rpm.

v) TORQUE CHARACTERISTICS - Basic requirement included establishing whether the engine is capable of a reasonable flat torque and whether there is a noticeable and viable improvement in the fuel efficiency - which shall endorse, moving from crankshaft to trilobate design makes sense.

4) BASIC ENGINE DETAILS – **Revetec 2.4 litre**

a) The 2.4 litre gasoline prototype weighs about 120 kgs without oil cooler, power steering pump, air compressor, AC compressor and damper.

b) A comparative table is provided between Revetec Engine and Toyota 1NZ-FXE

Parameters	**Revetec X4V2**	**Toyota 1NZ-FXE**
Capacity (liters)	2.4	1.5
Bore (mm)	108	75
Stroke (mm)	65	84.7
Compression Ratio [-]	10	13
Max Power (kW) @ rpm	68 @ 3700	48 @ 5000
Max Torque (Nm) @ rpm	203 @ 3000	102 @ 4000
Torque (Nm) @ 2000 rpm	184	84
Torque (Nm)/liter @ 2000 rpm	77	56
BSFC (g/kW-h)	207	225
Valve Train	8V OHV (Pushrod)	16V DOHC VVT-i
Fuel Injection	Sequential PFI	Multi Sequential PFI
Intake	Stainless Steel	Long Branch Plastic
Ignition	Dual Waste Spark	Quad Direct Fire
Parameters	**Revetec X4V2**	**Toyota 1NZ-FXE**
Engine Cycle	Otto cycle	Atkinson Cycle
Overall Dimensions (HxWxD) mm	520x750x400	680x595x680
Outside Dimension Volume (liters)	156	224

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5) ENGINE TESTING AT PEUS TESTING TEST BED

a) Revetec provided a 2.4 litre 68 kW gasoline engine with a peak torque capability of 203 Nm over the speed range of 1250 to 3600 rpm to Peus which was inturn was connected to a Schenck 350 kW DC Dynamometer running on Automator-Laufzeitunmgebung software for measuring engine performance;

b) Peus Testing utilised Fourier Transform Infrared Reader (FTIR) SESAM 111 from Peus Testing hardware to measure and record emission data.

6) OBSERVATIONS / RESULTS

a) <u>FREE RUNNING PHASE</u> - AL observed that the 2.4 litre Revetec engine can run without a crankshaft and produce power and the fundamental design-concept seems basically sound and workable; trilobate cam design of Revetec seems a strong candidate for replacing typical IC crankshaft based engines and can produce power reasonably efficiently in addition to being lighter.

b) The torque as claimed by Revetec was reasonably flat.

7) BSFC AND OTHER ENGINE CHARACTERISTICS

a) FIRST TEST - During the engine to dynamometer connection phase, the engine was run for short periods of time to establish / confirm connectivity with the instruments / programmer / computer. During one of those periods, the engine was accidently run by the DC dynamometer (which has an inbuilt high power direct drive motor) without the ignition on, the oil pump on, the coolant on, for about 15 to 30 minutes; this resulted in some damage to the engine (as the noise was noticeably more) but it was confirmed by Revetec team that the test may proceed.

b) TEST BED MEASUREMENT ANALYSIS - Lambda Measurement / Peus Controller / Revetec Engine Management system - in this test facility, the second major deficiency was the emission / performance and more importantly lambda measurements had no closed loop control (run by independent controllers) which resulted in fuel variations for a given torque / rpm - the lambda had to be adjusted manually till optimal fuel consumption was achieved (lean mixture) while the engine was running and the measurements were continually recorded by the Peus controller on auto controller mode. This resulted in unnecessary data being recorded each at different time levels; it was therefore collectively decided by Peus and Revetec that all data will be recorded and the corresponding data that reflected the actual situation at the correct value of lambda will then be tabulated for analysis. The attached data contains all recorded measurements including those during calibration - those highlighted were taken into consideration. In order to avoid this type of situation, future measurements will be made once the parameters are set (as done in AL) and then either recorded manually or programmed accordingly.

c) The following table elucidates the data collated by the team of Revetec at Peus.

Sl. No.	Engine Speed (rpm)	Torque (Nm)	Power (kW)	BSFC @ PEUS, 2.4 L Testing (g/kW-h)
1	1515	91	14.4	273
2	1825	87	16.6	220
3	2215	90	20.9	238
4	2510	80	21.0	246

8) ENGINE STOPPAGE DUE TO COMPONENT FAILURE

a) During the second test, the throttle was continuously oscillating by about 20 to 25% (up and down), which resulted in the engine rpm and torque hunting all over. It was first thought that the engine throttle mechanism was the problem and several corrections were tried with no solution. Later the engine dynamometer was run with the engine disconnected and the problem was found to be with the dynamometer. This was traced to software error in the dyno-controller: the regulator motor in the DC dynamometer was programmed at full mode – this was later adjusted and the oscillation eliminated. The engine was reconnected to the dynamometer. During this phase of problem identification, which was spread over an hour, the engine was subjected to several cyclic stress loads (in view of the oscillating loading conditions) between the engine and dyno (the engine trying to rev up while the dyno trying to brake and vice versa) Peus and Revetec engineers decided to test the engine only upto 50 to 75% load as this oscillating loads could have induced high stresses to the engine components.

b) During a test run programmed for 2500 RPM at 10% load, the engine was revved above 2800 rpm by Peus engineer and corrected down rapidly – while this was effected, the flywheel suddenly sheared off from the crank plate – It was found that during the course of this investigation, the front engine mounting bolts had not been tightened by the test-bed engineers which resulted in additional high vibration.

c) The emergency stop was activated, the engine stopped and interestingly the dynamometer continued to run probably due to is high inertial loads.

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d) Engine was partially dismantled and the critical components observed for failure / wear / tear. The engine was found in good condition except for damage to the balance shaft bush bearing – which was probably caused due to the bush bearing seizing during the first dry run besides the sheared flywheel. The most probable cause for flywheel shear failure was due to the oscillating loads imposed by the dynamometer and the loose engine mounting bolts. The trilobate and other gears were observed for any wear and tear – visual observation revealed no damage.

e) After a detailed discussion with all engineers and analysis of data with one and all, Mr. DC concluded.....

   i) that Revetec engine has potential for AL,

   ii) BSFC and Torque results were positive even though the test run was short,

   iii) engine was dismantled and the basic approach and design was found to be sound – has definitive performance potential over and above current typical IC engine,

   iv) further added that this Peus dynamometer was not ideal for this Revetec testing and suggested that further testing be carried out in one of AL's test bed.

f) All parties agreed to the above; it was decided to carry on further tests in AL's test bed in India, and then customize the engine to AL's conditions.

9) SUMMARY OF TEST RESULTS

a) **CONCEPT** – Fundamentally it was agreed that moving from crankshaft to trilobate design makes sense for several applications starting with DG sets for AL; however more work needs to be done which should take about 30 to 45 days.

b) **BSFC** – As per ARAI information, BSFC of 2.4 litre gasoline engine is about 255 to 280 g/kwh at full load. Revetec at part load of 60% in Peus has shown a BSFC of about 220 g/kwh. Orbital Australia confirmed that during their testing phase, the BSFC value of Revetec 2.4 litre engine was about 207 g/kwh at full load (2000 rpm).

c) **TORQUE CHARACTERISTICS** – During the short test-run, it was found that the torque was relatively flat – potential possibilities for further improvement through modification of trilobate profile and/or as per requirement is possible and a must. From previous data collected at Peus, at 2200 rpm, Revetec showed a torque of 150 Nm compared to 120 Nm of a typical IC engine – comparatively higher than most IC engines.

d) **ANALYSIS – TECHNOLOGY** – It was agreed that the basic concept seem more mechanically efficient than a conventional crankshaft and as a result can provide potential fuel savings in the range of 10 to 20% approximately over and above that provided by current conventional combustion engine.

e) **DURABILITY** – Despite the high cyclic loads imposed by the dynamometer, the engine internal components did not show any damage (visual observation); however, more material discussions with Revetec engineers is required to ensure durability.

10) **OTHER DETAILS**

a) It was proposed to test the engine further at AL facility to get a better grip of all the radical characteristics that this engine has to offer.

b) The Engine Construction was relatively found to be simple in comparison to other IC engines; this should make productivity relatively simpler in comparison. Being a lighter engine, engine can be mounted in the back of a truck – a possibility worth exploring.

c) A decision will be taken after discussion with AL team on the issue of using rotary fuel pump or CRDI (CRDI is preferred by Revetec)

d) Revetec and Ashok Leyland held extensive discussions concerning the manner in which the parties can best use their resources and skill sets to collaborate for the purpose of integrating Revetec's patented Bottom End Mechanical Advantage System within a series of engine variants of Ashok Leyland to primarily improve the BSFC, get a flat torque, reduce the size and weight of Ashok Leyland engines by 15-30% while improving both fuel consumption and emissions by between 20-30%;

e) Revetec agreed that it will take total responsibility for the following:

i) Complete the testing of the X4V2 engine in AL test bed as required by AL;

ii) Design the bottom end / take full responsibility for total design; performance. Emission and reliability of each customised engine variant built in Ashok Leyland. Such engine variants will be prepared for a variety of fuel types / variants including but not limited to Diesel, CNG Gasoline etc as required by AL;

f) Revetec will inturn requires Ashok Leyland to make available all resources as are necessary for the test completion, design and customisation process to take place;

The undersigned parties hereby acknowledge witnessing the testing of the 2.4 litre gasoline Revetec prototype and have viewed the results which are attached to these minutes and confirm that all the technical parameters have been reasonably recorded and understood as per the assertions made by Revetec Technologies India Private Limited in Peus testing.

Signature of Participants

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Ramesh Santhanam, Head Projects

Michael Howell Smith

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