CERTIFICATE OF TESTING

CUSTOMER:	**GSPK Multifuel Technology**	CUST REF:	**MAN (RTS)**
	GSPK Technology Park	JOB NUMBER:	**GSP0103**
	Manse Lane	ISSUE No.	**1**
	Knaresborough, N.Yorks.	TEST START:	**22nd June 2006**
	HG5 8LF	TEST FINISH:	**24th June 2006**
ISSUED TO:	**Mr. David Abbott (M.D.)**	PAGE:	**1 of 6**

Title:	Comparative fuel consumption tests diesel vs LPG mix on a MAN type 414 6x2 (Euro3) tractor unit with a GSPK diesel-gas system
Test standard(s):	LTC and GSPK defined procedures
Test piece description:	MAN 414 6x2 tractor unit (RTS Ltd. vehicle regd. no. X.896.NNO)

OBJECTIVES:

1. To determine the likely fuel cost savings on typical long-haul distribution work for a MAN tractor unit with a GSPK LPG system with an optimised LPG control map.
2. To quantify the increase in engine torque and maximum power (if any) with the optimised LPG control map (compared with the diesel baseline)

CONCLUSIONS:

1. A 10-mode test, which simulated running at motorway speed (56mph RSL) and at 80km/h for A-roads and dual-carriageways, was used to measure the % fuel cost savings at typical steady state engine load conditions for this vehicle (Fig.1). By applying weighting factors based on the typical operating patterns for this vehicle to those results, an overall fuel cost saving in service of 12.1% was predicted (Fig.2).
2. The greatest %age fuel cost savings were made at moderate power levels (20, 30 and 50% demand) with smaller savings at high power levels (70% demand). (There is no saving at 0% demand level because there is no fuel delivery at zero demand).
3. During simulated motorway running at nominally 56mph (RSL speed) with the engine developing 160kW power at the wheels, this vehicle showed a 12.2% fuel cost saving when running on diesel/LPG mix with the optimised control map (LEY2_150_D360) when compared with the diesel baseline (see Fig.1, mode 2).

	Author	Checked	Authorised
Signature			
Name	Steve Hughes	Dave Coxhead	Martin O'Leary
Job Title	Senior Engineer	Consultant	Director
Date	11th September 2006	12th September 2006	12th September 2006

mi Technology Group Ltd, Aston Way, Leyland, Preston PR26 7TZ, United Kingdom
T: +44 (0)1772 422911 F: +44 (0)1772 621466 E:mit-uk@mi-technology.com
Registered in England No. 2888007

CONCLUSIONS: (continued)

4. When running on diesel/LPG mix with the optimised LPG map installed there was virtually no increase in the maximum engine power (as measured at the road wheels) when compared with the diesel baseline for this vehicle.

   There was however, a significant increase in engine torque (as measured by tractive effort) and power between 900 and 1400 rpm, which will enhance the driveability of the vehicle. The maximum torque (tractive effort) was 14.7% greater and occurred at 1200 rpm on diesel/LPG mix, as opposed to 1400 rpm on diesel only.

5. There was no significant increase in exhaust gas temperature when running with diesel/LPG mix when compared to the diesel baseline. The maximum exhaust gas temperature on the diesel full load power curve was 582 deg.C at 800 rpm and the maximum temperature on the LPG full load power curve was 577 deg.C at 1000 rpm.

TEST METHOD:

The test vehicle supplied was from the RTS (Road Transport Solutions) Ltd. fleet,

Instrumentation was fitted to the vehicle to measure engine speed, inlet manifold boost pressure, exhaust gas temperature, diesel and LPG fuel consumption rates and LPG vapour pressure and record them on a data logger. Road speed and tractive effort were logged from the chassis dyno. The vehicle was installed on the SAC dyno. (rolling road) at LTC and tested under precisely controlled engine speed and load conditions.

The vehicle's baseline power curve was measured in 13th gear (7-LO) on diesel only prior to the LPG map optimisation (see Fig.3). It was then measured again on diesel/LPG mix with the optimised map (Ley2_150_D360) installed (see Fig.4). Engine speed, road speed, tractive effort, inlet manifold (boost) pressure and exhaust gas temperature were measured and power at the wheels was calculated from road speed and tractive effort. The tractive effort curve equates with the engine torque curve.

A fuel mapping exercise was carried out in top gear using a 10-mode test to compare the fuel consumption rates of 4 alternative LPG fuel maps with the diesel baseline. This test used the 2 predominant road speeds 50 mph (80 km/h) and 54 mph (87 km/h) at 5 engine load (demand) levels. The RSL on this vehicle, set nominally to 90 km/h, gave an actual road speed of 87 km/h on the dyno. The 5 demand levels (70%, 50%, 30% 20% and 0%) were chosen based on GSPK's evaluation of a typical journey on long-haul distribution with the same vehicle type.

The optimum fuel map was chosen that gave the lowest total fuel cost based on £0.83 / litre for diesel and £0.30 / litre for LPG (BP quoted bulk fuel prices). (see Fig.1). Diesel and LPG consumption rates (litres/hour) were calculated for each of the 10 modes with that optimised map and compared with the diesel baseline.

Note: Demand level (%) is one of the control parameters from the GSPK system and correlates with engine manifold (boost) pressure, rather than with engine torque output.

From these results a prediction of fuel cost savings in service operation was made by applying weighting factors to each mode, based on an analysis by GSPK of a sample of typical journeys with a similar truck (see Fig.2).

RESULTS:

10-mode test at 2 engine speeds corresponding to 56mph and 50mph in top gear and 5 demand levels (engine load) derived from GSPK statistical analysis of typical journeys.

Fig.1 Fuel cost savings with optimised map (Ley2_150_D360) on 10-mode test

Fuel type and map used	GSPK demand level set	GSPK demand actual	Engine speed rpm	Road speed km/h	Tractive effort kN	Boost press. bar	Exh. gas temp deg.C	Gas valve open	Diesel used litres	LPG used litres	Total fuel litres	Power at wheels kW	LPG % by volume	Relative fuel cost	Cost saving on LPG
Diesel	70	71	1358	86.9	8.09	1.24	472	0	0.920	0.008	0.928	195.3	0	£0.77	0
Ley2_150_D360	70	63	1358	86.9	8.06	1.14	463	150	0.680	0.528	1.208	194.6	43.7%	£0.72	5.6%
Diesel	50	51	1358	87.0	6.48	0.93	447	0	0.760	0.008	0.768	156.6	0	£0.63	0
Ley2_150_D360	50	44	1358	87.0	6.48	0.83	433	150	0.490	0.498	0.988	156.6	50.4%	£0.56	12.2%
Diesel	30	30	1359	87.4	4.62	0.58	397	0	0.570	0.002	0.572	112.2	0	£0.47	0
Ley2_150_D360	30	28	1359	87.4	4.64	0.54	391	122	0.370	0.260	0.630	112.6	41.3%	£0.39	18.7%
Diesel	20	20	1359	87.6	3.35	0.36	350	0	0.430	0.001	0.431	81.5	0	£0.36	0
Ley2_150_D360	20	19	1359	87.6	3.32	0.35	348	101	0.290	0.247	0.537	80.8	46.0%	£0.31	11.9%
Diesel	0	0	1359	88.0	1.42	0.13	269	0	0.250	0.000	0.250	34.7	0	£0.21	0
Ley2_150_D360	0	0	1359	88.0	1.42	0.13	269	0	0.250	0.000	0.250	34.7	0.0%	£0.21	0.0%
Diesel	70	70	1257	80.2	8.70	1.23	493	0	0.910	0.012	0.922	193.8	0	£0.76	0
Ley2_150_D360	70	62	1257	80.2	8.66	1.13	500	150	0.670	0.568	1.238	192.9	45.9%	£0.73	4.3%
Diesel	50	50	1257	80.5	7.08	0.93	485	0	0.750	0.005	0.755	158.3	0	£0.62	0
Ley2_150_D360	50	44	1257	80.5	7.15	0.82	461	150	0.490	0.536	1.026	159.9	52.2%	£0.57	9.1%
Diesel	30	30	1257	80.9	5.20	0.60	432	0	0.570	0.003	0.573	116.9	0	£0.47	0
Ley2_150_D360	30	26	1257	80.9	5.15	0.53	415	119	0.380	0.341	0.721	115.7	47.3%	£0.42	11.9%
Diesel	20	20	1257	81.1	3.92	0.38	382	0	0.450	0.000	0.450	88.3	0	£0.37	0
Ley2_150_D360	20	18	1257	81.1	3.92	0.35	373	100	0.310	0.234	0.544	88.3	43.0%	£0.33	12.3%
Diesel	0	0	1257	81.4	1.72	0.13	288	0	0.250	0.003	0.253	38.9	0	£0.21	0
Ley2_150_D360	0	0	1257	81.4	1.72	0.13	288	0	0.250	0.003	0.253	38.9	1.2%	£0.21	0.0%

Weighting factors (from GSPK analysis of journeys with a similar vehicle and operation) were applied to these results to predict fuel cost savings on long haul distribution work.

Fig.2 Predicted in-service fuel cost savings based on results from 10-mode test

Mode / Speed / Demand	Weight factor %	Diesel used (weighted)	LPG used (weighted)	Diesel cost (gas off)	Diesel cost (gas on)	LPG cost (gas on)	Total cost (gas on)	%age cost savings	% Diesel reduct'n	% LPG by volume	Total fuel Increase
1 - 87	5	4.60	0	£3.82							
70%		3.40	2.64		£2.82	£0.79	£3.61	**5.3%**	26.1%	43.7%	30.2%
2 - 87	25	19.00	0	£15.77							
50%		12.25	12.45		£10.17	£3.73	£13.90	**11.8%**	35.5%	50.4%	28.6%
3 - 87	25	14.25	0	£11.83							
30%		9.25	6.50		£7.68	£1.95	£9.63	**18.6%**	35.1%	41.3%	10.1%
4 - 87	5	2.15	0	£1.78							
20%		1.45	1.235		£1.20	£0.37	£1.57	**11.8%**	32.6%	46.0%	24.6%
5 - 87	1	0.25	0	£0.21							
0%		0.25	0		£0.21	£0.00	£0.21	**0.0%**	0.0%	0.0%	0.0%
6 - 80	5	4.55	0	£3.78							
70%		3.35	2.84		£2.78	£0.85	£3.63	**3.8%**	26.4%	45.9%	34.3%
7 - 80	5	3.75	0	£3.11							
50%		2.45	2.68		£2.03	£0.80	£2.84	**8.8%**	34.7%	52.2%	35.9%
8 - 80	18	10.26	0	£8.52							
30%		6.84	6.138		£5.68	£1.84	£7.52	**11.7%**	33.3%	47.3%	25.8%
9 - 10	10	4.50	0	£3.73							
20%		3.10	2.34		£2.57	£0.70	£3.28	**12.3%**	31.1%	43.0%	20.9%
10 - 80	1	0.25	0	£0.21							
0%		0.25	0.003		£0.21	£0.00	£0.21	**-0.4%**	0.0%	1.2%	0.0%
Totals	100%			**£52.75**	£35.35	£11.05	**£46.40**	**12.1%**	83p/ltr	30p/ltr	

Fig.3 Baseline engine power curve – diesel only

Fig.4 Engine power curve with optimised LPG fuel map (LEY2_150_D360)

Fig.5 Power curve data - Diesel baseline

Engine speed (rpm)	Road speed ave (km/h)	Tractive effort ave (kN)	Boost pressure (bar)	Exhaust gas temp (deg.C)	Power at wheels (kW)	LPG cons rate (l/h)	Diesel cons rate (l/h)
800	28.7	15.1	0.56	582	120.3	0.00	34.20
900	32.2	16.0	0.74	579	142.7	0.00	39.86
1000	35.7	16.5	0.94	572	163.9	0.00	45.90
1100	39.3	16.4	1.11	556	178.8	0.00	50.70
1200	42.9	16.7	1.28	537	199.5	0.00	56.10
1300	46.4	17.0	1.43	519	218.8	0.00	61.20
1400	50.0	17.0	1.52	506	236.7	0.00	66.34
1500	53.7	16.3	1.58	491	242.5	0.00	68.66
1600	57.3	15.8	1.68	482	250.6	0.00	72.00
1700	61.0	14.8	1.66	472	250.3	0.00	73.03
1750	62.3	14.2	1.63	460	246.3	0.00	73.03
1800	64.3	13.7	1.60	439	244.7	0.00	74.06
1850	66.2	13.1	1.58	449	241.6	0.00	73.54
1900	68.1	12.8	1.58	461	242.1	0.00	74.83
2000	71.9	11.5	1.47	440	229.0	0.00	71.70
2100	75.7	10.1	1.37	429	211.4	0.00	68.66
2150	79.3	-1.2	0.15	212	-25.9	0.00	11.31

Fig.6 Power curve data - optimised LPG map

Engine speed (rpm)	Road speed ave (km/h)	Tractive effort ave (kN)	Boost pressure (bar)	Exhaust gas temp (deg.C)	Power at wheels (kW)	LPG cons rate (l/h)	Diesel cons rate (l/h)	Combined cons rate (l/h)	% LPG in total fuel used
800	28.7	15.5	0.57	553	123.2	0.31	34.46	34.77	*0.9%*
900	32.3	16.8	0.78	572	150.4	9.21	40.11	49.32	*18.7%*
1000	35.6	18.6	1.08	577	184.4	11.26	46.80	58.06	*19.4%*
1100	39.1	19.3	1.35	570	209.4	17.74	50.91	68.66	*25.8%*
1200	42.6	19.5	1.52	551	231.1	12.75	56.57	69.33	*18.4%*
1300	46.3	18.7	1.58	527	240.1	10.34	61.20	71.54	*14.5%*
1400	50.0	17.7	1.63	507	245.9	5.66	66.34	72.00	*7.9%*
1500	53.7	16.6	1.65	489	247.6	4.32	67.89	72.21	*6.0%*
1600	57.1	15.8	1.67	477	250.2	3.81	71.49	75.29	*5.1%*
1700	60.9	14.8	1.66	467	250.6	4.42	73.03	77.45	*5.7%*
1800	64.2	14.1	1.64	462	251.5	4.22	73.54	77.76	*5.4%*
1850	66.0	13.4	1.61	459	246.7	9.26	72.51	81.77	*11.3%*
1900	67.8	13.1	1.60	460	247.6	12.86	74.06	86.91	*14.8%*
2000	71.5	12.4	1.54	453	245.6	15.38	70.97	86.35	*17.8%*
2100	75.4	10.3	1.39	431	215.1	1.80	67.89	69.69	*2.6%*
2150	78.9	0.8	0.15	214	-17.4	0.46	12.86	13.32	*3.5%*

TEST VEHICLE DETAILS:

MAN F2000 414 6x2 tractor	regd. no. X.896.NNO (RTS Ltd. fleet)
Engine manufacturer / Type	MAN TGA 410 bhp (Euro 3 spec.)
Transmission type	EATON type RTS 15316A (16-speed manual)
Rear axle ratio (single red'n.)	3.05:1
Drive axle tyre size	315/80R22.5 Roll. circ. 3.28m (305 revs/km)

TEST EQUIPMENT:

Results were obtained using a programmable data logger to record the following:

Engine speed, manifold (boost) pressure, diesel used total, LPG (liquid) used total, LPG vapour pressure, exhaust gas temperature (plus engine water outlet, fuel inlet, drive axle oil and ambient temperatures for monitoring and control purposes)

Dyno (road) speed and tractive effort were logged direct from the dyno and power at wheels was calculated from these two parameters.

Cumulative fuel used (litres) was displayed continuously on the data logger for both diesel and LPG and the fuel consumption rates were calculated by recording the change in total fuel used over a fixed time interval and converting to litres per hour.

Diesel consumption was measured with a JPS FM10 positive displacement fuel meter (5cc resolution) and the LPG (liquid) consumption was measured using GSPK's own Endress and Hauser "Coriolis" mass flow rate measurement system (1cc resolution). The pulsed outputs from both devices were input to digital counter channels on the data logger and displayed as cumulative total fuel used (in litres).

(Stock numbers of all instrumentation used is archived on the GSP0103 package sheet)

DISCUSSION:

LPG measurement: It was not possible to verify the accuracy of the new LPG fuel measurement (Coriolis) device at the time of testing as there are no practical means available for checking the calibration of the device with LPG liquid under pressure. Cross-checks between the amount of LPG (litres) used to refuel the vehicle and that recorded by the E & H device indicated an uncertainty (error band) of +/- 5%. It is more likely that the Coriolis device is over-reading slightly, so the fuel cost savings indicated are more likely to be pessimistic / conservative and the fuel cost savings should therefore be slightly better than indicated.

There is a lack of devices or systems available "off the shelf" at present for precision measurement of LPG liquid mass flow at low flow rates and this Coriolis system is believed to be the best currently available for the purpose. The level of uncertainty with this device will reduce with further testing and calibration experience.

Vehicle speed: When running the vehicle in cruise control mode against its own road speed limiter (RSL) on the dyno. the indicated vehicle speed from the tachograph was nominally 3 km/h (2 mph) higher than the actual dyno. road speed (i.e. dyno. speed 87 km/h for vehicle indicated speed of 90 km/h / 56 mph). This is due to two factors:

a) there is inherently greater tyre slip on the smooth steel dyno. rollers than when running on highway (so that the indicated speed will be higher at any given speed)

b) there is a tolerance on the calibration accuracy of the vehicle tachograph, allowing for the normal variation in tyre rolling circumference which changes with imposed load and tyre wear/tread depth (so that the vehicle indicated speed error increases when laden and also as the tyre wears)