AUTOMATION TECHNIQUE FOR THE VALIDATION AND RE-CALIBRATION OF BASE AIR AND FUEL ON THE VEHICLE

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ABSTRACT

Increasing software complexity, a growing number of vehicle variants, extensive diagnostic requirements, and stringent emission regulation requirements have significantly increased the calibration complexity. Shorter vehicle development times put further pressure on the development tasks. Technical advances have resulted in more tasks being done using simulation and on engine beds. But in-vehicle testing is still a crucial activity because human perception is still a key factor to assess vehicle calibration quality. But vehicle testing is expensive, so new techniques for in-vehicle calibration are required to reduce the time and cost without reducing calibration quality.

In a vehicle development program, EMS calibration starts with base calibration optimization on the engine dynamometer. Once complete, the data must be validated on the vehicle and if necessary recalibrated. During the vehicle development phases several hardware and software modifications are necessary, which means this vehicle validation cycle must be repeated many times. To reduce the amount of time required to perform the tests, and to improve the accuracy of the calibration process, this in-vehicle calibration was automated, using the guided calibration methods provided by INCA-FLOW.

In this paper we describe how guided calibration was developed to automate in-vehicle steady state calibration on the chassis dynamometer. We detail the benefits over manual calibration, which included improved calibration accuracy, reduced calibration time and reduced cost. In addition, the developed tests could be reused on different vehicles with minimal effort. This allowed the calibrators to spend more time on preparing test methodologies, and allowed a new calibration method to be developed that further reduced the calibration time on the vehicle.

INTRODUCTION

In a conventional base engine optimization, there are many calibration tasks to be performed on the engine dynamometer to achieve the intended performance, fuel consumption and emissions. Fig.1 shows the elements of the base engine calibration. During development stages of the engine and vehicle, these tasks need to be repeated because of changes to hardware, calibration and even ECU software changes. Traditionally these tasks have been performed manually which consumes a lot of test effort and cost.

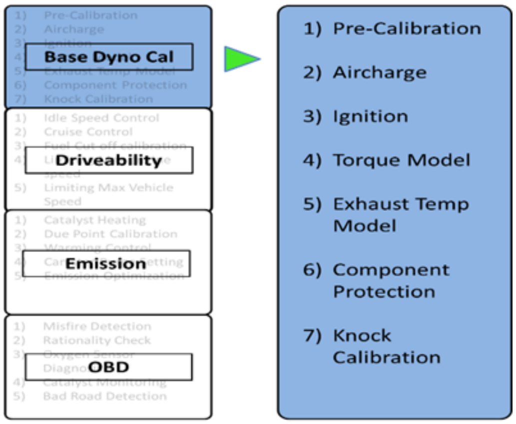


Fig.1 Typical elements of Base Calibration tasks

Increased complexity of system design and technological advancement of the vehicle systems, increases the degree of freedom of the calibration task to be performed. Optimizing the calibration with the increased number of interactions between these calibration parameters in a shorter span of engine development, without compromising the accuracy of the data mandates the use of automatic test. Tata Motors are evaluating the automation of the in-vehicle base calibration with INCA-FLOW. This paper presents the first results of the evaluation.

1. AUTOMATION OF CALIBRATION ACTIVITIES

1.1 THE NEED FOR AUTOMATION

Many calibration tasks consist of a number of steps carried out in a sequence. In addition, during the development phase several hardware and software modifications occur resulting in the basic calibration tasks having to be repeated for each configuration changes. This generates a large amount of work for the calibration engineer, not only to run the calibration sequences, but also to collect and analyze the measure data. This takes time, and increases the cost of the development work. There is also a risk to the quality of the calibration data, because manually controlling the operating conditions for some tests is not always easy, and it is also easy to make mistakes following the test sequences. Automating calibration routines can result in reduction in calibration times and associated costs, while increasing the calibration quality by better controlling test conditions and reducing test mistakes.

1.2 AUTOMATING WITH INCA-FLOW

One problem with automating calibration routines is the actual script creation. Scripts have to be created in a coding language, which the calibration engineer must learn before programing. Often the best calibration engineers are not always the best software coders and vice-versa.

The difference with INCA-FLOW as an automation tool is that the coding is graphical in the form of flow charts. The tool was designed for calibrators to use because:

a. It facilitates the automation of procedures without any software development;
b. The graphical representation of algorithms is easy to understand even for less experienced calibrators;
c. The graphical representation provides for easy maintenance of the calibration procedures;
d. Libraries with comprehensive collections of ready-to-use MCD methods allow for very efficient design.

Using INCA-FLOW results in a change to the calibration approach, see fig.2. More time has to be used to plan and prepare the tests, but this results in less time actually doing the test on the vehicle.

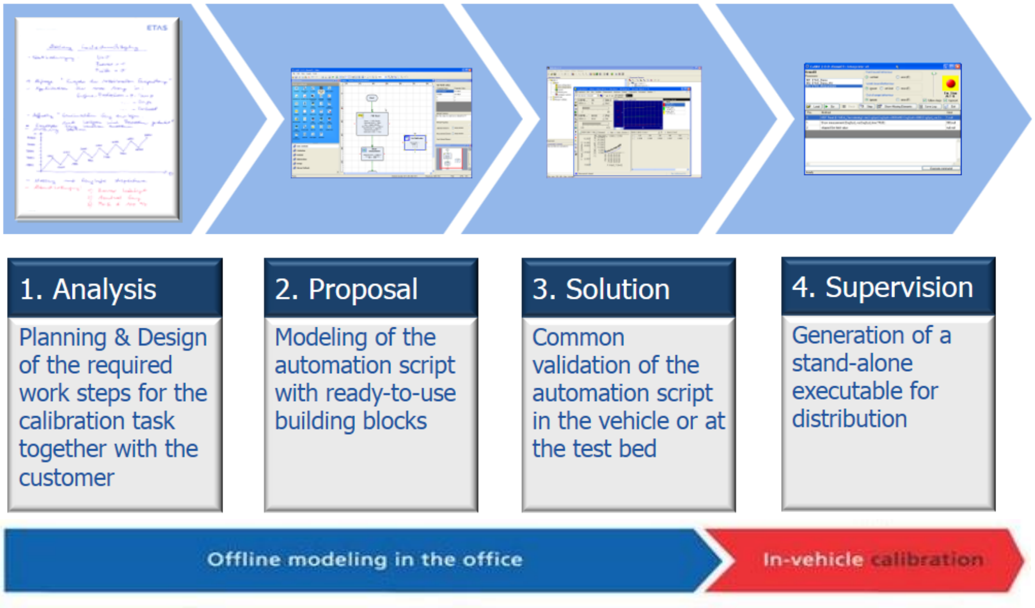


Fig.2 The calibration preparation steps using INCA-FLOW

By using the test automation from INCA-FLOW, the calibration parameters can be changed online. The data recording can also be automated and analyzed directly by the tool. The nature of the automation means each repeated step is done in a consistent way, reducing the variability in test results and reducing the risk of test errors. The operating point of the engine for each validation point can also be kept stable by using the internal PID controller in the tool to adjust the throttle online.

2. BASE CALIBRATION VERIFICATION AND RE-OPTIMIZATION USING SEMI AUTOMATIC METHOD ON CHASSIS DYNAMOMETER

2.1 The test Setup

A chassis dynamometer, sometimes referred to as a rolling road, measures power delivered to the surface of the "drive roller" by the drive wheels. The vehicle is often parked on the roller or rollers. This roller is driven by the vehicle and the output measured thereby. A controlled vehicle chassis dynamometer helps to run the vehicle in lab as if driving in actual road condition. Semi-automated vehicle test at chassis dynamometer was achieved by running the vehicle on a controlled chassis dynamometer and changing the engine parameter by using control interface software program INCA-FLOW3.2 which is an add on to INCA (existing EMS ECU calibration software).

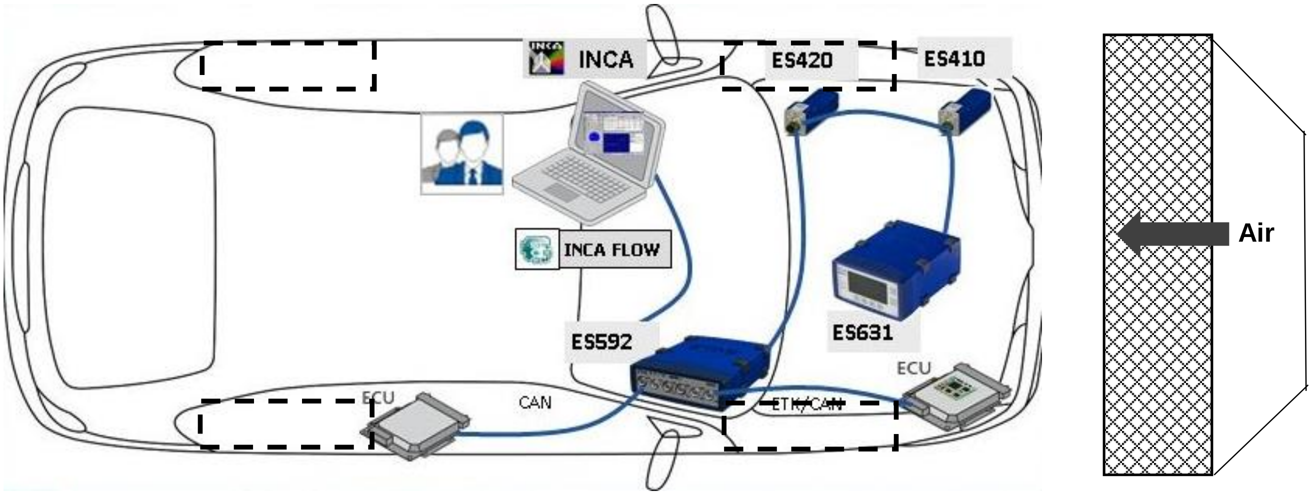


Fig.3 Test setup for Semi-Automated Vehicle operation

Fig 3. shows the devices and services required for semi-automated vehicle test system on chassis dynamometer. The critical parameters are measured through engine ECU (e.g. Engine rpm, Throttle position, and λ) and External monitoring variables are communicated to ES592 through Analog input units ES631, ES420 and ES410 (e.g. Air / Exhaust Temperature, Actual λ). The outputs are calculated from the controllers (usually Spark advance offset for MFB50 and Throttle control and Injector gain for λ and temperature control) are fed into EMS ECU via the ECU – INCA control interface automatically.

2.2 Task Description

Once the engine bench calibration is performed, typical next task is to migrate the calibration data to the vehicle level and verify for any deviation and re-calibrate if required. This task is done by running the vehicle on a chassis dynamometer and perform steady speed verification. Fig.4 shows typical elements of calibration maps to be verified in steady speeds. In this paper we will concentrate on the calibration of the primary and secondary air charge maps, as these were the subject of the evaluation.

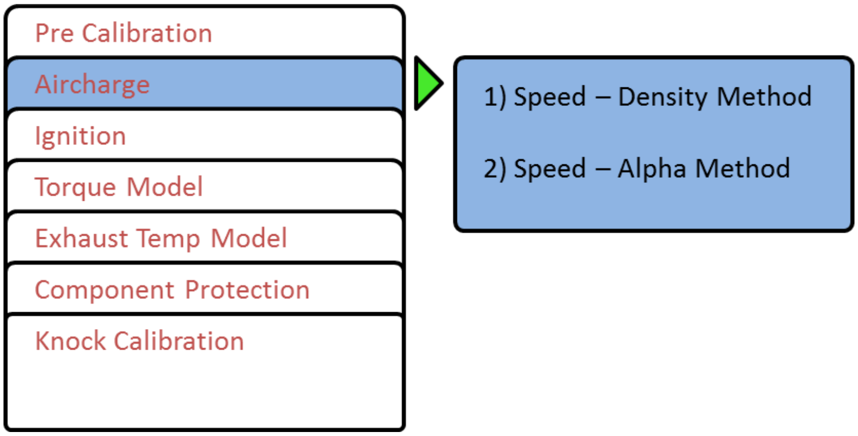
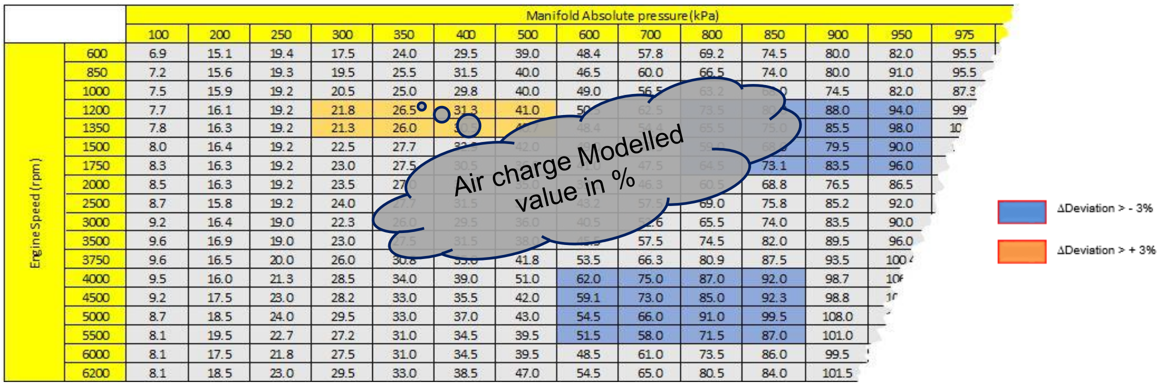


Fig.4: Elements of the base steady state verification on vehicle

2.3 Manual Method of Base Air Charge Verification:

The primary air charge represents the amount of air inducted in to the engine modelled using an engine speed and air density method. The way this is calibrated is to run the engine with open loop fueling. At each speed load point compare the measured λ value with the target λ value. This represents the actual deviation between modelled air charge to actual air charge intake at that operating point, provided fuel compensation factors are not deviating.



	Manifold Absolute pressure(kPa)													
Engine Speed (rpm)	100	200	250	300	350	400	500	600	700	800	850	900	950	975
600	6.9	15.1	19.4	17.5	24.0	29.5	39.0	48.4	57.8	69.2	74.5	80.0	82.0	95.5
850	7.2	15.6	19.3	19.5	25.5	31.5	40.0	46.5	60.0	66.5	74.0	80.0	91.0	95.5
1000	7.5	15.9	19.2	20.5	25.0	29.8	40.0	49.0	56.5	63.2	68.0	74.5	82.0	87.3
1200	7.7	16.1	19.2	21.8	26.5	31.3	41.0	50.5	62.5	73.5	80.5	88.0	94.0	99
1350	7.8	16.3	19.2	21.3	26.0	30.5	40.7	48.4	54.4	65.5	75.0	85.5	98.0	10
1500	8.0	16.4	19.2	22.5	27.7	32.5	42.0	49.0	[illegible]	59.0	68.0	79.5	90.0	
1750	8.3	16.3	19.2	23.0	27.5	30.5	36.0	41.0	47.5	64.5	73.1	83.5	96.0	
2000	8.5	16.3	19.2	23.5	27.0	[illegible]	35.0	[illegible]	46.3	60.5	68.8	76.5	86.5	
2500	8.7	15.8	19.2	24.0	27.7	31.5	[illegible]	43.2	57.5	69.0	75.8	85.2	92.0	
3000	9.2	16.4	19.0	22.3	26.0	29.5	36.0	40.5	52.6	65.5	74.0	83.5	90.0	
3500	9.6	16.9	19.0	23.0	27.5	31.5	38.0	45.5	57.5	74.5	82.0	89.5	96.0	
3750	9.6	16.5	20.0	26.0	30.8	33.0	41.8	53.5	66.3	80.9	87.5	93.5	100	
4000	9.5	16.0	21.3	28.5	34.0	39.0	51.0	62.0	75.0	87.0	92.0	98.7	10	
4500	9.2	17.5	23.0	28.2	33.0	35.5	42.0	59.1	73.0	85.0	92.3	98.8	1	
5000	8.7	18.5	24.0	29.5	33.0	37.0	43.0	54.5	66.0	91.0	99.5	108.0		
5500	8.1	19.5	22.7	27.2	31.0	34.5	39.5	51.5	58.0	71.5	87.0	101.0		
6000	8.1	17.5	21.8	27.5	31.0	34.5	39.5	48.5	61.0	73.5	86.0	99.5		
6200	8.1	18.5	23.0	29.5	33.0	38.5	47.0	54.5	65.0	80.5	84.0	101.5		

Fig. 5: Typical Primary Air charge map to be verified

So the first task is to determine which speed load points need to be calibrated, which involves testing each point. If an error in the λ is found to be outside a 3% tolerance, then the primary air charge map is adjusted until the λ error is under 3%. Typically, recalibration is only required on areas where our actual and modelled air charge deviates more than acceptable limits due to changes in the external factors (viz. Exhaust pressure, fuel temperature, fuel pulsation, pressure pulsation in the intake manifold, etc.). In general, we don't have any compensation factors applied for these changes. Fig. 5 shows the typical number of speed load points for the primary air map that need to be verified manually.

Once the primary air charge map is calibrated then secondary air charge can be calibrated. This represents the inducted air amount modelled using engine speed and throttle opening. The secondary air model value should be within 3% of the primary air charge model value. If it is outside this range, the air charge map corresponding to the secondary air charge is calibrated until the values are within 3%. Primary challenge is to achieve calibration accuracy of ±3% in both primary and secondary air charge. An additional challenge is the calibrator must monitor and control the inlet manifold pressure manually using the accelerator pedal at the same time as making the calibration changes.

The maps to be verified have 16 x 12 breakpoints in our case, which means there are more than 190 points where steady state grid verification needs to be performed. This verification has to be repeated again with multiple vehicles. Finally, out of this huge volume of data the calibrator has to fix the final data with some statistical optimization method. The cumulative effect results in a very high test effort, and a large volume of data to be analysed. If there are any design, dataset, or software functionality changes then the entire process needs to be repeated again. Accommodating all these iterations with in the span of the project time line is a challenge.

2.4 Steady state based Automation method:

To evaluate the INCA-FLOW guided calibration methods, we developed a semi-automatic algorithm for verification and calibration on the chassis dynamometer. This method is called semi-automatic since the dynamometer controller was not interfaced with INCA-FLOW at this stage. The operating points such as dyno speed, engine speed and gear positions were set externally, but the throttle was controlled by the INCA-FLOW algorithm to achieve the targeted inlet manifold absolute pressure. Once the program is started, the control algorithm will automatically open INCA, initialise the ECU and switch to working page for calibration access. When the engine speed is set, the program will ensure the operating conditions like desired engine speed, gear and accelerator pedal position are correctly set before executing the test. Then the program will automatically cycle through each load breakpoint on the calibration map, continually checking whether the other operating parameters are still in range. If during the test these parameters go out of the range, the test execution will be aborted.

For the evaluation, calibration verification algorithms were developed for the following modes

1. Base Air charge verification Speed-Density method (Primary air charge)
2. Base Air charge verification N-alpha method (Secondary air charge)
3. Base Air charge calibration Speed-Density method (Primary air charge)
4. Base Air charge calibration N-alpha method (Secondary air charge)
5. Load Ramp methods

In the INCA-FLOW script, the verification and calibration process were separated. In the verification mode once the speed is set on the dyno, the script cycles through each load point on the map, checking the primary and secondary air charge results in terms of any deviation to target values. If a deviation is detected, the script will automatically move on to calibration mode and calibrate the map set point to bring the value within tolerance. The calibration is done by iterating the map point up or down until the desired output values are reached. Once all the load points have been measured, the script asks to proceed for the next speed point, the users can exit at this point if they want.

2.5 The Load Ramp based Automation Method

One of the most time consuming parts of the process was the need to validate each speed load point, even though many did not actually need to be calibrated. So to further speed up the process, a faster way of validating the maps is required. Because the automated script was able to accurately control the targeted variable, it was possible to ramp up the load in steps and the results are recorded to a measure file. After the test is completed, the measure file (.dat) is analysed, and it can be established quickly, which speed load points require further calibration.

3. RESULTS:

3.1 Automatic Method Result

3.1.1 Test result with Steady Speed method:

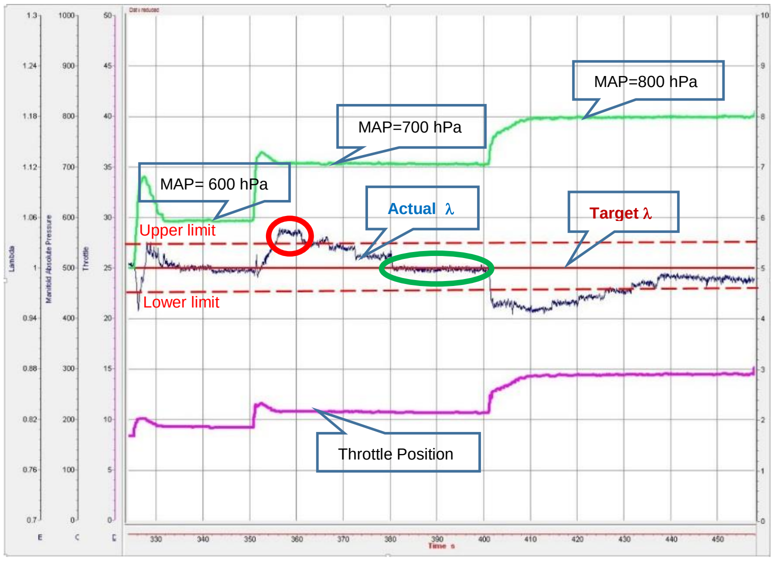
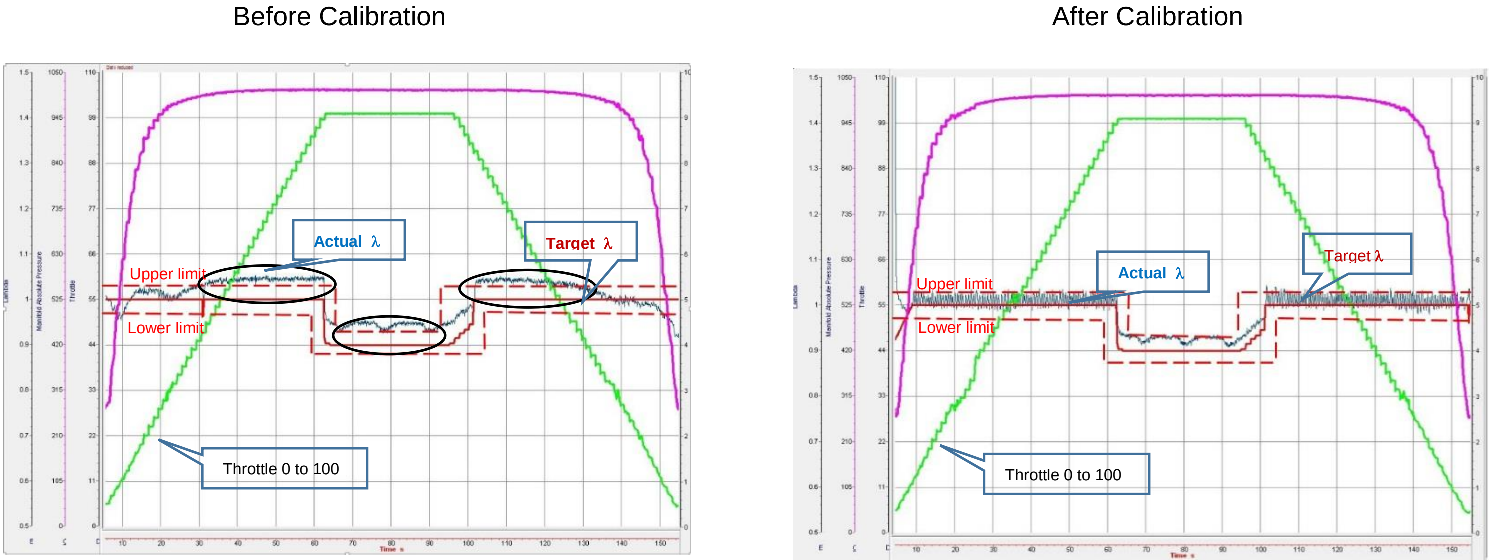


Fig.6: Primary Charge calibration by Automatic method

Fig.6 shows a recording of the primary air map calibrated using INCA-FLOW. The red encircled region represents the actual measurement where λ is deviating more than the target limit (i.e. > 3%). INCA-FLOW has iterated the map value until the λ value agrees with the target λ shown by the green encircled region. What is interesting to note is the green line at the top, the inlet manifold pressure, which stays constant throughout each test point due to the on line throttle control possible with INCA-FLOW.

3.1.2 Test results with Load Ramp Method:

In this method, first data was recorded with Load Ramp method without making any calibration changes to the primary air charge map. After this verification, all the areas with a λ deviation of more than 3% were identified. Next step is to run an automated steady state calibration as explained in section 3.1.1 and λ deviations are corrected to be within the target limit (i.e. 3%). Then the Load ramp method is performed again to verify and confirm the calibration data set. Fig.7 shows the result with automated Load Ramp Method.



Before Calibration

After Calibration

Fig.7: Primary Charge Verification by load ramp method

The advantage of this method is that the speed load points that need calibrating can be quickly determined, further reducing the on vehicle test time.

3.2 Calibration Effort Improvement

By using automated calibration method, the time taken for one speed load point was found to be 40% shorter compared to the manual method. One of the main reasons for this improvement is the ability of the INCA_FLOW script to accurately control the manifold pressure while at the same time performing the calibration changes. Refer Fig.8 for the time to set, calibrate and measure one process point in both modes.

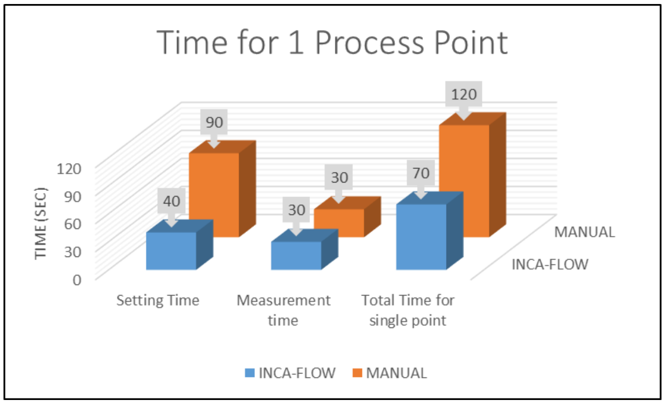


Fig.8 Time comparison for one process point.

Fig.9 shows the time required to do a complete primary air charge calibration manually and using INCA-FLOW.

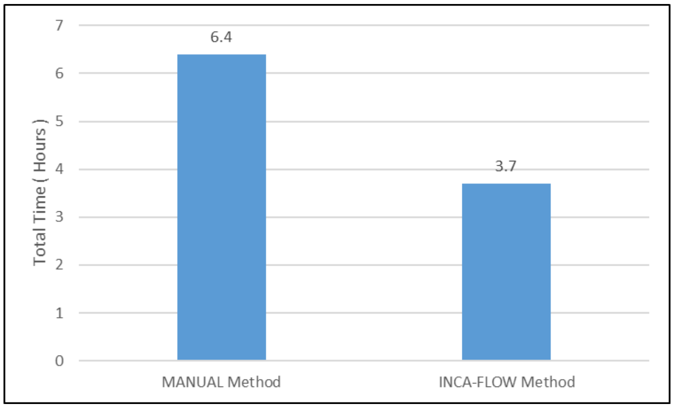


Fig.9 Total time comparison between two methods

This represents a 40% reduction of test time required on the vehicle. This directly represents a cost saving in terms of better resource planning, resource utilization. From the above result, automatic method is proven to be proficient method to reduce calibration effort & time effectively.

CONCLUSION

Based on the above developmental work, the authors are of the following opinion on use of Automatic algorithm using INCA-FLOW for Vehicle calibration work on chassis dynamometer.

1. INCA-FLOW is a suitable automation tool for the automation of in-vehicle base calibration verification and calibration.

2. Better repeatability and re-produce ability of the test results were achieved with the automated method.

3. Accuracy of the automatic test results was better compared with the manual test method. This is because the automated tests provide consistent results, while the manual method can have variations caused by human error and differing skill levels of the engineers.

4. 40% calibration efficiency improvement was achieved by using semi-automated test method using INCA-FLOW.

5. The use of this semi-automated test set up combined with in-cylinder pressure measurement will further enhance the capability of the calibration process to Ignition set point verification and recalibration.

6. A fully automated set up can be achieved once the input from chassis dyno controller to the INCA-FLOW algorithm is integrated. This will enable one to do hands free Vehicle level steady speed calibration on chassis dynamometer.

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DEFINITIONS, ACRONYMS, ABBREVIATIONS

DoE: Design of Experiments

MFB50: Mass burn fraction

EMS: Engine Management System

ECU: Electronic Control Unit

MAP: Manifold Absolute Pressure

A/F ratio: Air to Fuel ratio

λ : Actual Air fuel Ratio / Theoretical Air fuel ratio

Fig.: Figure