ABSTRACT

This paper describes the development of Tata Nano Engine Management System and the related electrical and electronics architecture. The design criteria for the electrical and electronics architecture are discussed in detail in the body of the paper.

When the Nano project was first conceived, the existing low cost car in India was not affordable by common people. The Nano project was targeted for a family of 4 which was using a two wheeled vehicle for commuting, irrespective of the season. For engineers, it was difficult to conceive the idea of the Nano vehicle and powertrain. How do you design a benchmark which meets both Indian and export needs and should also be extremely low in cost? There was no low cost car available either for the Nano to benchmark against.

It was also clear that the strict pollution regulations existing in India could not be met without an Engine Management System and thus the focus centered on a low cost Engine Management System (EMS).

EMS development consisted of two main parts:

1). **Hardware** : Development of safe, reliable but low cost hardware which meets all requirements and fits in the E&E architecture was a challenge.

2). **Software** : Finalizing the software requirements, designing and testing all functions within the limited memory and processor speed was critical. The common “V” cycle model was followed for the development of EMS.

In Nano, to reduce the development time and cost, modern tool chains were used extensively. The initial phase, called the alpha phase, utilized the Tata Motors (referred to as Tata hereafter) in-house Model Based Design process including HIL testing. In the second phase, the production phase, the EMS system supplied by Bosch was used. Tata performed functional testing of the released production software in HIL, participated in the function design, function review and calibration.

INTRODUCTION

As there was no benchmark for Nano (Figure 1), the first challenge was to define a full fledged low-cost car. The idea behind this car was to provide transportation for a family of 4, under all weather conditions. For this, the team needed to understand the typical Indian customer requirements. Firstly, the vehicle's fuel economy should be higher than that of the existing lowest cost car, which would give Nano a considerable advantage. Secondly, while fuel economy was critical, launching performance and drivability could not be compromised, particularly the acceleration at traffic signals. Thirdly, it was decided to optimize the car mainly for city and urban driving, thus the top speed target for the car was set at 105 km/h. In an Indian city, around 90% of the time the average speed on roads is about 50 km/h, and the top speed achieved ranges from 60 - 80 km/h. Lastly, the comfort level inside the Nano should meet the requirements of an Indian family. Specifically it should have comfortable sitting capacity of 4 persons with huge leg room. It should also be comfortable for both tall and short persons.

The Engine for the Nano was developed in-house. This reduced the cost of the engine to the end customer. The challenge was to develop an engine that would not only fit into limited space but should also deliver high power and torque in natural aspirated form. All the components were designed and developed from scratch. It was decided to go ahead with a 625cc, two cylinder engine (Figure 2).
In the Nano project, due to the time and cost constraints, it was clear that a different approach was required to meet the EMS design & development requirements. The conventional development cycle of going with a particular vendor in prototype and production stage would take too long in Tata Nano project because vendors were not able to meet cost constraints, as the existing components at the time of Nano development were not meeting the target cost of the vehicle. Even the basic requirements were changing almost everyday. Considering the criticality of timeline, it was decided to have the EMS development in two phases. First was prototyping using in-house EMS, then in the second phase going ahead with the chosen vendor.

In the first phase, the focus was on building and running an alpha prototype engine, economically and quickly. An in-house EMS was used so that all engine and vehicle level data can be acquired and then demonstrated to the marketing department and company management for approval. This gave management additional inputs and time to bring down the EMS cost estimates from vendors without sacrificing development time. The data collected served as inputs to the prototype stage with the vendor chosen for the production phase.

In the second phase, which focused on the productizing the Nano, the EMS was further developed to meet safety, emission, comfort and drivability requirements without escalating target cost. At the same time, the EMS needed to
fit well in the vehicle E&E architecture. Suitable ECU, sensors, actuators, high tension leads and ignition coils were required to fulfill the Indian EMI-EMC requirements. Special diagnostic systems that are easy to operate but rich in features and diagnostics needed to be developed. It needed to meet the requirement of diagnostics in remote areas and roadside without any computer or external tool.

FIRST PHASE: RUNNING ALPHA NANOS

For quick feedback on engine power and vehicle drivability, it was decided to proceed with in-house rapid prototyping EMS. For the engine ECU, Pi OpenECU was chosen, as this was available off the shelf in Tata. Most of the other EMS components were arranged from existing Tata car projects (crank, temperature, manifold air pressure, lambda sensors) and a few new components were developed (Ignition coil, high tension lead). The control algorithm were developed and modified in Tata to meet the 2 cylinder, 625 cc wasted spark configurations. The engine control algorithms developed in MATLAB and Simulink were implemented automatically using code generation. The ECU, flashed with the executable software, was tested in the HIL set up running an engine and vehicle model to verify both its normal functionality and its behavior in abnormal conditions. The tests, including applying stress by resetting the controller, shorting power and supply lines to ECU, short and open circuit tests for various sensors and actuators, were completed thoroughly in HIL. Use of already established tool chain helped in reducing the cycle time for software development and testing. It also shortened the calibration time in engine test bed. The Nano engine model was run and tested with these basic calibrations.

After HIL testing, bench testing was done by connecting all physical sensors and actuators in actual engine wiring harness and put on test set up.

Both on the test bed and on vehicle, drivability, deceleration fuel cut-off, idle calibration, transient calibration development was done. Eight alpha Nanos were built and run, each using a rapid prototyping ECU. These Nanos were tested on a test track for drivability, engine power, brake performance, suspension, and NVH. Apart from design optimizations of engine capacity, brake and suspension, reduction in development time in this crucial first phase was achieved. It also helped management decide on various parameters like vehicle layout, cooling design and engine capacity upgrade, early in the development process.

As the in-house prototyping team acquired the necessary knowledge and skills of EMS, it helped Tata to negotiate and collaborate effectively with suppliers. As Nanos were getting tested on various aggregates without problem, purchasing managers used the time to negotiate. This activity also helped answer many questions which the project team had at the start of the Nano project, like “Is the engine capacity and configuration adequate? Is the engine torque curve as per expectation? Would the idle noise and vibration be acceptable to customers? What electrical architecture should be chosen so that it meets customer expectations and target cost?”. This is especially important since there was no benchmark vehicle available for Nano.

Thus, for Nano, the situation demanded a solution which was not tried earlier in Tata’s Engineering Research Centre, Pune, India.

NANO E&E ARCHITECTURE

Throughout the project, every requirement was considered critical and only the absolute necessary requirements (i.e. safety, pollution, drivability, comfort & reliability) were considered in the development of this value car. The Nano E&E architecture relevant to engine management system was divided into 5 parts as mentioned below:

1). Engine Management System including the Engine Control Unit
2). Battery
3). Alternator
4). Starter
5). Instrument cluster

As shown in figure 3, Engine Management System (EMS) hardware consists of sensors, actuators and Electronic Control Unit for the engine (referred to as the engine ECU hereafter). Performance, reliability and cost target were the main criteria for selecting these sensors, actuators and ECU.

The vehicle speed sensor was selected from the third party. The vehicle speed sensor was integrated to the instrument cluster directly. Since the vehicle speed sensor is of the Hall Effect type, one supply pin and one ground pin would have been required on the engine ECU. Since the vehicle speed information is required by the instrument cluster for display purpose, it was decided to process the vehicle speed signal in the instrument cluster control unit and hard-wire the processed vehicle speed signal to the engine ECU.

To reduce the complexity and cost of the electrical and electronics systems of Nano, the instrument cluster was not designed with a CAN interface. All signals were hardwired to the cluster ECU.

ENGINE MANAGEMENT SYSTEM DEVELOPMENT FOR PRODUCTION

Based on the experience gathered during the in-house alpha Nano EMS development, requirements for quotation were
prepared and enquiries were floated. For production, the Bosch Value Motronic system was chosen. This ECU had a two layer PCB and could meet Euro IV pollution norms with EOBD. Instead of a CAM sensor phase detection software was introduced in platform. Engine ECU was operating MIL and HTWL in the instrument cluster. To meet the timeline for vehicle SOP, Tata and Bosch worked jointly to calibrate the software in test bed and in vehicle, as per agreed RASIC.

Higher vibration levels are inherent to a two cylinder engine. The Nano EMS team modified the existing Value Motronic Platform through software and calibration to reduce the vibration level. To reduce the complexity of managing variants of engine ECU, only one software and calibration was used for all varieties of engines and vehicles which were catering to Bharat Stage II, Bharat Stage III, AC and non-AC Nanos.

Using the Nano diagnostic tool, detailed information about fault could be available to the service engineer. Powerful diagnostic capability (with freeze frame details) for workshop use was made available. For diagnosing in remote places or roadside, “Blink code” were developed based on Tata design. In the diagnostic software, all the relevant ECU data were displayed. Real time engine operating parameters, online monitoring and recording of data facilities were provided in the diagnostic tool. Customers were very happy to take a printout of the average fuel consumption and average vehicle speed for the last 10 drive cycles using Nano diagnostic tool. This feature helped to convince and educate the customers about fuel efficient drive cycles.

The EMS team performed component level testing of sensors, actuators and engine ECU including the fitment, vibrations were done. Vehicle integration tests including wiring harness short/open, abnormal functional behavior, low & high voltage and temperature tests were carried out.

For new modifications or upgrades to control algorithms, both Bosch and Tata worked jointly. Calibration for the engine on engine test beds and vehicles were also carried out jointly.

**HOW THE EMS COST WAS REDUCED?**

EMS components such as ignition coil, throttle position sensor and crank sensor, were specifically designed and developed to meet the target. Other sensors were taken from existing platforms so as to have a proven-in-field and reliable EMS system. The numbers of sensors were kept to the
minimum in Nano. The starter motor and alternator were also specifically designed and developed for Nano. The alternator on Nano was not providing load feedback to the engine ECU, so software strategies were developed to estimate the load on engine. For example, parasitic loads on the engine during idling were taken into consideration, and as a result, the target idle speed was increased before engaging air condition compressor clutch. The increased engine speed resulted in a lower idling noise & vibration and better battery charge balance (air condition blower consumes additional current).

Bosch implemented the torque structure model for EMS strategies. Tata EMS control algorithm structure was different from Bosch torque based control structure. Tata used a model based control algorithms approach to build alpha Nanos. To reduce cost arising out of complexity of the software strategies; torque structure was activated only in regions where it was absolutely a must. For example, when engine was in idle state, ECU had control on all three parameters including air quantity (by operating stepper motor more or less open), fuel injection quantity (by opening injector for more or less time) and spark angle. Software complexity was reduced so that it takes less memory size (flash) and less calibration time. The EMS team worked to size down a considerable number of two dimensional maps of the default software functions in the Bosch-provided engine ECU software. Furthermore, Bosch trimmed the functions which are not required for Nano variant (i.e. 2 cylinder engine, wasted spark ignition, no CAM sensor) to reduce the size of the software and increase availability of microcontroller computing resources. Only one software and calibration set is used for all varieties of engines that include Bharat Stage II, Bharat Stage III, AC and non-AC nanos. It reduced the cost of part handling in plant and in the service field.

As for hardware, Bosch developed an entirely new engine ECU to meet Tata Motors Ltd demand for cost. Bosch combined a number of previously separate Application Specific Integrated Circuits (ASIC) into a single ASIC. Expensive EEPROM was replaced by emulated ROM. Bosch developed a 2-layer PCB for the engine ECU (instead of the conventional 4 layers PCB) that met all the Indian EMI/EMC standards and passed all Tata internal requirements. The number of pins in the ECU was decided on the basis of the functional requirements of the Nano engine and without keeping many spare pins. The ambient pressure sensing chip was removed from the existing PCB layout to save cost. All the related calculations (i.e. ambient pressure learning) were done based on an ambient pressure sensor estimator implemented in the embedded software. Deletion of the CAM sensor signal detection circuit in the ECU and the processing functionalities in the software helped to reduce cost. Knock sensor processing circuitry was not populated. These were innovative ideas considering the fact that Bosch came up with it in the year 2005 which has become industry standard since then. Other EMS hardware components were also deleted to save cost. It was decided that wasted mode ignition system would be used and so there was no need to go for 2 individual ignition coils which are usually required in a non-wasted spark mode operation. CAM sensor was also removed from bill of material, and in its place, software was used to determine phase of engine. Knock sensing was not considered for cost reason, instead calibration was done carefully. Costs associated with wiring harness, connectors, clamps associated with these sensors and actuators were saved. Almost all of the indicator lamps in instrument cluster are LEDs which reduced cost.

The combination switch of Nano is developed in India with a very simple design so that it meets the target cost. Cost effective small capacity fuel pump was developed to meet the Nano engine requirements. Battery for Nano vehicle was developed in India to lower the cost. Charge balance trials were done in rainy nights and on busy road conditions to confirm that the battery was not depleting even if the engine was idling most of the time when the current demand from headlamp and wiper motor were high.

To reduce the development cost and time, much of the software and hardware development was done locally in India.

**SUMMARY/CONCLUSIONS**

When the uncertainties in project requirements were high and development time was short, our experience in Nano proved that rapid prototyping on model based design was very useful. We strongly felt that to develop a car which did not have a benchmark, rapid prototyping added high value by providing useful data to decision making authority. For Nano, this model based methodology, apart from developing Engine Management System, helped in development of brakes, vehicle resistance coefficients, gear ratio for drivability and engine size, NVH and cost optimization.

At low price, stringent requirements were met for the Sensors, Actuators and ECU. Hardware was replaced by reliable software to reduce cost wherever possible. In ECU modified ASIC, ambient pressure circuit, CAM & Knock signal processing, circuits were removed. EMS components like Knock sensor, CAM sensor, Ignition coil, Connectors and wiring saved the cost. In the instrument cluster ECU, cost of CAN trans-receiver was saved. Without sacrificing functionalities, the software was downsized and implemented in a simpler way. Customer friendly diagnostics were also developed to be used by the service technicians of Nano.

All in all Tata succeeded in developing a value car satisfying all the customer and regulatory norms in India.
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ACKNOWLEDGMENTS
The authors acknowledge contributions to the content of this paper from S Govindarajan, Deputy General Manager, Advanced Engineering Department, Tata Motors Ltd, Pimpri, Pune.

DEFINITIONS/ABBREVIATIONS

E&E  Electrical and Electronics
HIL  Hardware In Loop
HTWL  High Temperature Warning Lamp
Pi  Pi Shurlock
CAN  Controller Area Network
IVN  In Vehicle Networking
MIL  Malfunction Indication Lamp
OEM  Original Equipment Manufacturer
PCB  Printed Circuit Board
AC  Air Conditioning
RASIC  Responsibility, approval, support information chart

ECU  Electronic Control Unit

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