A MATLAB post-process method of vehicle cold start data

Feng Qian¹, Peng Li²,³, Neng Zhu² and Xiaowei Xu¹

¹School of Automotive and Transportation Engineering, Wuhan University of Science and Technology, Hubei 430081, China
²Key Laboratory of High Performance Ship of Ministry of Education, Wuhan University of Technology, Hubei 430063, China
³E-mail: leepengwhut@163.com

Abstract. Gasoline vehicle cold start calibration is one of the important calibration work content. And the important evaluation criterion of cold start is start time, overshoot, undershoot. At present, the calibration engineers in most companies mainly use ETAS/INCA software to record test data, and then use MDA software to analyse start time, overshoot and undershoot. But the cold start test data is so huge, so the post-processing efficiency is very low. Facing this problem, the post-processing tool of cold start data based on MATLAB is established. With this tool, the huge amount of data can be processed efficiently, and key start mode or start-stop mode can be distinguished clearly. So it can greatly improve the post-processing efficiency of cold start data.

1. Introduction

The cold start calibration is one of the main tasks of vehicle calibration. Comparing with the steady-state operating conditions, although the cold start procedure is short, it is the worst stage of combustion performance. A large number of studies [1-4] have shown that, CO and THC emissions during the starting phase of gasoline vehicles at ambient temperature emissions account for about 60% to 80% of the entire test cycle; at a low temperature of -7°C, the THC and CO emissions generated during the cold start phase are even more than ten times higher than normal temperature [5-10]. Therefore, in order to decrease the emissions of gasoline vehicles, it is necessary to focus on the cold start phase.

The basic goal of cold start calibration of gasoline vehicle is to ensure that the vehicle starts normally, quickly and smoothly at different temperature. Most optimizations are applied to ensure the cold start quality [11, 12]. And A large number of cold start tests are needed to reach this goal. At present, most companies and research institutes use INCA software developed by ETAS to record ECU data, then use MDA software to load data, and determine the cold start performance (starting time, overshoot, undershoot and so on) through “local amplification, manual point sweeping” method. However, due to the huge amount of cold start test data, this manual method is extremely inefficient. And there is no open literature to introduce high efficiency automotive post-processing method.

In the face of this situation, a data post-processing tool for gasoline vehicle cold start test is developed based on the MATLAB programming platform, which can process cold start data automatically and generate starting performance report. It can largely improve the cold start data post-processing efficiency.
2. Cold start procedure of gasoline vehicle

2.1. Cold start performance evaluation criterion

The start mode of gasoline vehicles can be divided into key start and start-stop mode. Key start mode is turning the key to the ignition-on, then the starter drags the flywheel to run, so that the engine speed increases and start ignition and combustion. Start-stop mode is an energy saving strategy, at this mode the engine can stop in idle condition, and then activates the starter by pressing the clutch pedal or releasing the brake, which lead to injection and ignition to increase the engine speed. The key start and start stop mode can be distinguished by the engine state flag (CoPTStNew_stEng) during the start. At key start, CoPTStNew_stEng changes from 1 to 5; and at start-stop mode, CoPTStNew_stEng changes from 6 to 5. And basic variables and parameters for cold start is listed in Table 1. The difference of engine state flag changing during the key start and start-stop mode are shown in Figure 1 and 2.

| Signal                | INCA Label                  | Default Value |
|-----------------------|-----------------------------|---------------|
| Engine stop time      | Time_since_stall|tabst_w         | 0             |
| Battery voltage       | Ext_uBattMes                | 12            |
| Engine speed          | Ext_nEng|nmot_w          | 0             |
| Coolant temperature   | Ext_tCoMes                  | 20            |
| Engine state flag     | CoPTStNew_stEng             | 5             |
| Battery capacity      | Ext_rBattSoC                | 85            |
| Target idle speed     | nstat|TqSys_nTarIdl    | 800           |
| excess air coefficient| Lambda|LA4:Lambda_Word | 1             |

Table 1. Basic variable list for cold start.

![Figure 1](image1.png)  
**Figure 1.** Engine state flag changes during key Start.

![Figure 2](image2.png)  
**Figure 2.** Engine state flag changes during start-stop.
Both start modes can be divided into three phases: start phase, after start phase, and warm up phase. Start phase is from the beginning of the battery voltage drop to engine speed reaching 800rpm; after start phase is from engine speed 800rpm to the time when cylinder heat exchange conditions is fully accomplished; warm up phase is from the end of the after start phase to the time when the coolant temperature increased slowly to reach nearly 80℃.

![Figure 3. Main evaluation indexes of cold start process.](image)

The main evaluation indicators of the cold start include the start time, the maximum speed of the start procedure and the overshoot, the minimum speed and the undershoot. Start time is an indicator to evaluate the rapidity of starting, and it refers to the time from the battery voltage drop to when the speed reaches 800 rpm, as shown in Figure 3; overshoot refers to the difference between the maximum engine speed and the target idle speed, and undershoot refers to the difference between the minimum engine speed and the target idle speed. According to different start time, overshoot, the start performance can be evaluated according to the criteria of Table 2 and Table 3. And the criteria are derived from automotive company, the company use it to evaluate and ensure the cold start quality. In Table 2, the start time note is determined by the start time and the coolant temperature at start. In Table 3, the overshoot note is derived from the overshoot. If the note is higher than 8, It means cold start quality is good.

### Table 2. Start time scoring criteria.

| Temperature (℃) | Start Time (s) |
|-----------------|---------------|
| -30             | 3.5 4.9 6.9 9.8 13.9 19.7 27.9 39.6 56.1 79.4 |
| -25             | 2.5 3.5 4.9 7.0 9.9 14.0 19.8 28.1 39.8 56.4 |
| -18             | 1.2 2.2 3.1 4.3 6.1 8.7 12.3 17.4 24.6 34.9 |
| -10             | 0.9 1.2 1.8 2.5 3.5 5.0 7.1 10.1 14.2 20.2 |
| -5              | 0.6 0.9 1.3 1.8 2.5 3.6 5.0 7.1 10.1 14.3 |
| 0               | 0.4 0.6 0.9 1.3 1.8 2.5 3.6 5.1 7.2 10.2 |
| ≥5              | 0.3 0.4 0.6 0.9 1.3 1.8 2.5 3.6 5.1 7.2 |

| Note(-)         | 10 9 8 7 6 5 4 3 2 1 |

### Table 3. Overshoot scoring criteria.

| Overshoot(rpm) | 14 20 29 40 70 120 180 |
|----------------|-------------------------|
| Note           | 0 1 1.5 2 3 4 5         |

| Overshoot(rpm) | 230 320 400 600 800 950 1300 |
|----------------|-----------------------------|
| Note           | 5.8 7 8 10 8.5 5             |

| Overshoot(rpm) | 1725 2000 2500 3000 3500 4000 |
|----------------|-------------------------------|
| Note           | 2.5 1.7 1 0.5 0 0             |
2.2. Raw data post-processing method

At present, most companies mainly use the MDA software to analyze the cold start data. Firstly, the data is partially amplified, and then search the starting point and end point of the cold start procedure manually, as shown in Figure 4 and 5, and finally calculate start time, Overshoot and other indicators. However, due to the huge amount of cold start test data, the data post-processing method is less efficient.

![Figure 4. Cold start and retarst test data (0~300s).](image)

![Figure 5. “Partially magnification, scanning manually” data post-processing method (242~243s).](image)

3. MATLAB-based data post-processing method

In order to solve the problem of low post-processing efficiency, a cold start test data post-processing tool is developed based on the MATLAB programming platform; INCA data can be automatically processed and an Excel analysis report can be generated. The report covers the information of vehicles status, ECU parameters related start procedure, start performance indicators, etc.

3.1. Post-processing tools calculation logic

The post-processing tool is written by MATLAB program code, and the logic of calculation is shown in Figure 6:

1) scan the INCA data folder, determine the number of cold start INCA files, and read the file name;
2) according to the INCA file name get the basic configuration of the vehicle, such as test date, engines, transmissions, etc.;
3) load the INCA data using the ‘mdfimport’ function to obtain the value of each measurement signal changing over time;
4) determine the start times of vehicle in one single INCA data based on the “Engine stopping time” signal, from which one start or restarts can be distinguished;
5) determine the beginning point of the start according to the sudden drop of the "battery voltage" signal;
6) read the value of each important parameter at the beginning of the start, including engine coolant temperature, ambient temperature, oil temperature, etc. It is useful to evaluate the start performance;
7) according to the "start stop activation flag" signal the start mode (key start or start-stop) can be determined;
8) determine the ending point of the start phase according to the "engine speed" signal when it reach 800rpm; and the maximum (Nmin) and minimum engine speed (Nmax) can be determined according to the "engine speed" too.

9) calculate the start performance indicators, including start time, overshoot, undershoot, etc.

10) export Excel report summary, covering INCA data basic information, vehicle configuration information, relevant state parameters at starting time, performance indicators for each start.

![Figure 6. The logic of the MATLAB post-processing tool.](image)

3.2. Load INCA files

The loading of INCA data is one of the basic functions of post-processing tools. The INCA data format is usually MDF, consisting of 9 mandatory blocks and two non-essential blocks. The existing 9 blocks are the identification block, the header information block, the text block, the data block, the data block, the channel block, the channel block, the channel conversion block, and the channel expansion block. The other two non-essential blocks are the program block and the trigger block. The CD block is a data block, recording time and signal data.

In MATLAB, the mdfimport function is used to parse the CD module in the MDF file to obtain the signal data and the corresponding time axis. Then the required signal data is exported to the workspace of MATLAB for subsequent calculation and analysis. The basic form of the mdfimport function call is as follows:

```
mdfimport(fileName,importlocation,signalselection,timevectortype,ratedesignation, additionaltext);
```
Where fileName is the INCA file name, and ‘signalselection' is the variable list that needs to be imported into workspace.

3.3. Calculation of the number of starts
The number of starts in one single INCA file is determined by scanning the "engine stop time", "engine speed" and "engine status flag" signals point by point. When the engine is started by key, the engine status flag "CoPTSt_stEng" is set to "3". When the engine is in start-stop mode, this flag is set to "7"; if the "CoPTSt_stEng" label doesn’t exist, the "engine stop time" label "tabst_w" is used to calculate the number of starts, the logic is as follows: when the engine is not started, the stop time will increase by seconds, if the engine is started, "tabst_w" will stop increasing, so when \(tabst_w(t+2)=tabst_w(t+1)=tabst_w(t)+1\), the number of start times increased by one. If the "engine stop time" does not exist, the number of start times is determined by engine speed signal, when engine speed suddenly exceeds zero the start times increase. The logic of start times is shown in Figure 7.

![Figure 7. The logic of start times calculation.](image)

Figure 7. The logic of start times calculation.

![Figure 8. The logic of determination of start time.](image)

Figure 8. The logic of determination of start time.
3.4. **Determination of start time**

The starting point of the start phase is defined as “the time when the battery voltage starts to fall”. In general, the battery voltage is 12V. At the time of engine start, the voltage will drop to less than 9V as the battery provides power to the starter. Since the vibration of the battery voltage can exceed 0.3V in normal condition when the engine is not started, this tool defines the beginning time when the battery voltage drops more than 0.3V within 0.01s. If the voltage signal does not exist, jump directly out of this procedure. The logic of determination of start time is shown in Figure 8.

3.5. **The distinction between key start and start-stop mode**

After the start time is determined, the start mode can be determined based on the Start-stop flag "B_stopz" or the engine state flag "CoPTSt_stEng". At the start phase, "B_stopz"=0 indicates that the start is key start mode, and "B_stopz"=1 means the start-stop mode; if "B_stopz" does not exist, the start mode is determined by the engine status flag. "CoPTSt_stEng"=3 means the key start mode, "CoPTSt_stEng"=7 means the start-stop mode.

3.6. **Overshoot, undershoot calculations**

After the beginning point of the start phase is determined, the ending point, overshoot, undershoot can be determined based on the engine speed signal by scanning point-by-point. When the engine speed increases to 800 rpm, the start phase ends and the time T_end is saved as the ending point. When the engine speed reaches the maximum and then starts to decrease and return to idle, the maximum value of engine speed is saved as NMAX, the minimum speed is saved as NMIN. The "target idle speed" signal "TqSys_nTarIdl" is load and overshoot, undershoot can be calculated using the following formula;

\[
\text{Overshoot} = \text{NMAX} - \text{TqSys_nTarIdl} \\
\text{Undershoot} = \text{TqSys_nTarIdl} - \text{NMIN}.
\]

According to the engine coolant temperature, starting time, overshoot, undershoot, etc., the start performance can be comprehensively scored.

3.7. **Calculation of start performance scoring**

According to the engine coolant temperature at the beginning time and start time, the starting time score can be calculated by following experienced formula form the automotive company:

\[
\text{Start\_Note} = \text{MIN}(7.664-2.873*\text{LN(Start\_Time)}) - 0.2*\text{MIN(T\_coolant, 5)},10) \\
\]

According to the formula, the lower the coolant temperature is, the shorter the starting time is, and the higher the starting scoring is.

3.8. **MATLAB data post-processing results**

After MATLAB tool finishing post-processing all INCA data, it will export all the start results to the Excel summary report. The Excel report contains 4 tables, the table "Model" is the initial template for data post-processing, the table "Essence" summarizes the data processing results for all key start mode in the INCA data, and the table "Start\_Stop" summarizes all the start-stop mode. And the data processing results specifically include the following contents.

1) INCA file name and post-processing time and date;
2) basic vehicle configuration information;
3) start times and important parameters at each start;
4) start time, maximum speed, minimum speed of each start and start comprehensive score and other indicators.

Table "Sheet1" lists several important indicators of each start (including key start and start-stop mode) in all the INCA data: including the start time comprehensive score (Note), the maximum engine speed (Nmax), the difference between the minimum engine speed and the idle speed (Undershoot), as
shown in Figure 9; and a line chart is drew to evaluate the cold start performance more clear and intuitive according to the start criteria: Note $\geq 8$, $N_{\text{max}} \leq 1600$rpm, Undershoot $\leq 60$rpm.

![Figure 9](image1.png)

**Figure 9.** Summary results of important evaluation indicators for cold start.

This post-process tool has the advantages of easy operation, fast processing speed, and export comprehensive summary report automatically, which can greatly improve the data post-processing efficiency of cold start calibration engineer.

### 4. Comparison of two post-processing methods

The comparisons of two post-processing methods are shown as Table 4. The developed MATLAB post-processing tool can quickly process cold start test data and distinguish between key start mode and start-stop mode. And the calculate step of this MATLAB tool is 0.01s, so the start time can be accurate to 0.01s, and the overshoot and undershoot accuracy can reach 1rpm. So the calculation accuracy is higher than manual definitions and handling. Besides when the M program of the tool starts running, the processing rate only depends on the hardware configuration of the computer. The original cold start data post-processing method can only be processed manually, and the processing efficiency is about 30s per start. With this tool the post-processing time is greatly reduced to approximately 2 seconds per start, which means the data processing efficiency increased by nearly 15 times and the output summary report is more comprehensive, and each start will be calculated without any omission. Besides the M program is editable, we can also add other emission data to the program, and analyze the emission of the pollution during the cold start by Integral algorithm.

| Post-Processing method | Processing rate | Start mode judge | Accuracy | Summary results |
|------------------------|-----------------|------------------|----------|-----------------|
| Manual                 | 30s per start   | Manully          | 0.1s     | Simple          |
| MATLAB tools           | 2s per start    | Automative       | 0.01s    | Detailed        |
5. Conclusions

Based on the theory of the start process of gasoline vehicles, this paper establishes a post-processing analysis tool for cold start data based on MATLAB platform. Compared with the original post-processing method, this post-processing tool is simple in operation, and the data processing rate increased 15 times, and it can generate excel summary reports automatically, which can significantly improve the data post-processing efficiency of cold start calibration engineers. It is used for mass post-processing analysis of cold start test data of vehicles.

Acknowledgements

This work was supported by the National Natural Science Foundation of China (No. 51679176). The author appreciates the support of School of automotive and transportation engineering (Wuhan University of Science and Technology).

References

[1] Borghate Yash. 2018 Cold start analysis and modeling of a direct-injection gasoline engine Master thesis of Michigan Technological University

[2] R Suarez Bertoa and C Astorga 2018 Impact of cold temperature on Euro 6 passenger car emissions Environmental Pollution 234 318-329

[3] Jason Lupescu, Lifeng Xu, Hung-Wen Jen, Amy Harwell, John Nunan, Chad Alltizer and Gregory Denison 2018 A New Catalyzed HC Trap Technology that Enhances the Conversion of Gasoline Fuel Cold-Start Emissions SAE paper 01-0938

[4] Komateedi Narayana Rao, Mi-Young Kim, Jinwoo Song, SeungChul Na and Hyun Sik Han 2018 Cold-Start Hydrocarbon Speciation and Trap Materials for Gasoline Engines SAE paper 01-0940

[5] Lifeng Xu, Jason Lupescu, Justin Ura, Amy Harwell, William A. Paxton, John Nunan, Chad Alltizer 2018 Benefits of Pd Doped Zeolites for Cold Start HC/NOx Emission Reductions for Gasoline and E-85 Fueled Vehicles SAE paper 01-0948

[6] Y Chao, X Chen, J Deng, Z Hu, Z Wu, L Liguang. 2018 Additional injection timing effects on first cycle during gasoline engine cold start based on ion current detection system Applied Energy 221 55-66

[7] Thirumal Valavan Harikrishnan, Abinav Sunder and John Hoard 2018 Study of Effects of Thermal Insulation Techniques on a Catalytic Converter for Reducing Cold Start Emissions SAE paper 01-1431

[8] Jiri Navratil 2018 Predicting and Minimizing Virtual Vehicle Cold Start Driveline Model with a Real-Time 1-D Gas Engine Code and Chemical Kinetics Aftertreatment SAE paper 01-1425

[9] Ran Wang, Jia Hui Li, Feng Qian Fast removal of pollutants from vehicle emissions during cold-start stage Open Chemistry 16(1) 468–472

[10] M Lapuerta, Ángel Ramos, J Barba and D Fernandez-Rodriguez 2018 Cold and warm-temperature emissions assessment of n-butanol blends in a Euro 6 vehicle Applied Energy 218 173-183

[11] Wang Wei, Yu Xiumin, Zhao Hongzhi, et al. 2012 An Experimental Study on the Effects of Exhaust Valve Timing on the Cold Start and Its Emission Performance of Gasoline Engine Automotive Engineering 1 26-29

[12] Li Liguang, Wang Zhensuo, Deng Baqing, et al. 2004 A study on Ignition and HC Emission of a Gasoline EFI engine During Cold-start Automotive Engineering 4 417-422