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Development, Implementation and Validation of ASC Algorithm for EMU Trains

Y. Buldu, E. Atabay and F. Kaya

UGES, ASELSAN
Ankara, Türkiye

Abstract

This paper presents the successful development, implementation and validation of the Automatic Speed Control algorithm for Electric Multiple Unit trains. The Automatic Speed Control function plays a crucial role in optimizing the performance and comfort of Electric Multiple Unit trains. This development activity begins with the design phase, where the Automatic Speed Control algorithms are developed to provide optimum speed control, increase energy efficiency, reduce driver fatigue and ensure passenger comfort. Using a PI controller for speed regulation, the algorithm improves speed control effectiveness by seamlessly integrating total resistance force estimation and allows real-time evaluation of changing slopes for improved performance. Once the algorithms are formulated, preliminary simulations are implemented in MATLAB-Simulink to evaluate the performance under various operating scenarios. Following MATLAB-Simulink simulations, the Automatic Speed Control algorithms are subjected to rigorous testing in both laboratory and on-train. While there are certain subsystems in the test set-up used during the tests carried out in the laboratory environment, other subsystems that are not present in the environment are simulated using the Hardware in the Loop methodology. Laboratory tests provide controlled settings to evaluate algorithmic behaviour and fine-tune parameters, while on-train tests provide insights into real-world validation and practical applicability. Improvement activities based on observed results are configured to optimize the algorithm by better adapting to dynamic operating conditions. The results presented here contribute to the continued advancement of railway automation technologies with implications for improving efficiency and sustainability in railway systems.

Keywords: automatic speed control, electric multiple unit, train control and management system , traction and braking, hardware in the loop , laboratory and field validation.

1 Introduction

ASC (Automatic Speed Control) serves as an optional feature designed to assist the train driver across various operational scenarios, including but not limited to: initiating movement, maintaining consistent speeds, adjusting speeds, and executing braking manoeuvres to come to a halt [1]. ASC function is a feature that operators need for reasons such as ensuring safety, reducing driver fatigue, increasing energy efficiency and ensuring train line compatibility. This feature effectively minimizes the risk of overspeed incidents by adhering to reference speed values, thus facilitating smoother and more efficient train operations.

The Automatic Speed Control (ASC) system uses an advanced feedback control algorithm to manage the speed and acceleration of trains, enhanced with predictive capabilities to address system delays [2]. Simulation analysis and data testing are performed to verify the performance of the control algorithm [3].

While automatic vehicle speed control system is reliable under normal conditions, it faces challenges from unpredictable factors such as disturbances, system changes and sensor noise. Even the smallest uncertainties can disrupt performance. The use of feedback control mechanisms such as PID controllers is vital to prevent disturbances and adapt to system changes. This protects against the negative effects of uncertainties by enabling the system to quickly correct deviations and maintain optimal performance [4]. Control systems using PID controllers offer superior quality control processes compared to those based solely on PI controllers, while systems with PI controllers have greater robustness to changes in object properties and are easier to troubleshoot. As a result, PI controllers, which strike a balance between sensitivity to changes and ease of implementation and maintenance, are often preferred in automatic control systems [5].

An Electric Multiple Unit (EMU) train is a type of train consisting of multiple carriages or carriages, each equipped with their own electric traction motors. EMUs require an ASC algorithm to optimize their speed control for enhanced efficiency and safety during operation. Considering the system's complex technology and variable operating environment, these steps are key to increasing stability and comfort during EMU operation [6].

In laboratory tests, the Hardware-in-the-Loop (HIL) setup simulates the real system, providing a comprehensive inspection. Additionally, in-train testing evaluates system compatibility by monitoring or recording signals from real units through testing software. This comprehensive approach ensures robust performance by verifying system functionality in a variety of environment [7].

2 Methods

In this study, an ASC algorithm model was developed as shown in Figure 1. The ASC Algorithm continuously receives train speed information and compares it with the reference speed that requested by the driver. If the current speed of the train is above the reference speed, the Central Control Unit (CCU) initiates braking. For this purpose, it reduces the speed of the train by sending a reference brake force signal to the brake system. Conversely, if the current speed of the train is below the reference speed, the CCU increases the speed of the train by sending a reference traction force signal to the traction system.

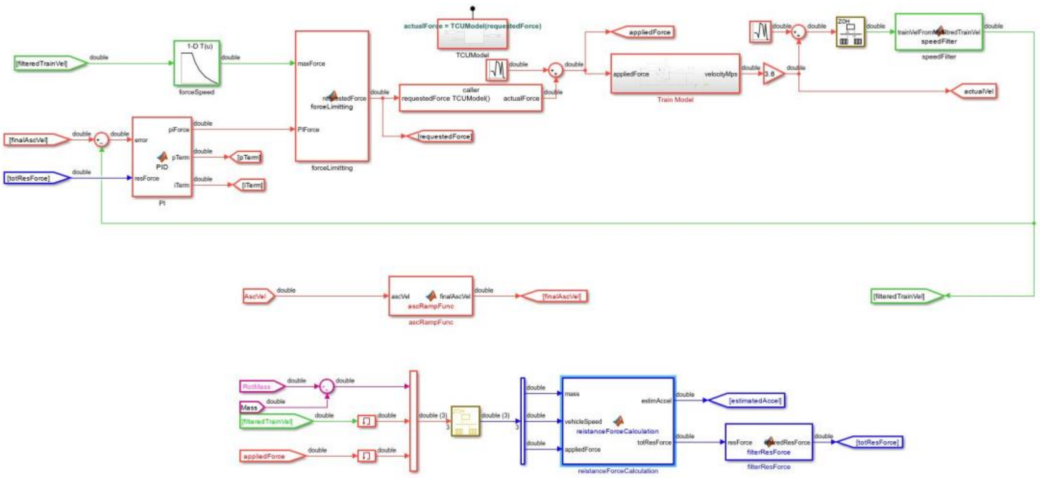

Figure 1: MATLAB Simulink model.

The main block diagram of the ASC algorithm is given in Figure 2. In the algorithm, firstly, the PI controller defined by Equation (1) is used to keep the train speed constant according to the reference speed value. However, since the train is used on a line with a slope of ±4%, the PI controller alone is insufficient to control the speed. Therefore, the PI output is collected after estimating the total resistance force that the train is exposed to. In this way, the ASC algorithm shows better performance.

$$u(t) = K_P . e(t) + K_I . \int_0^t e(t) . dt \tag{1}$$

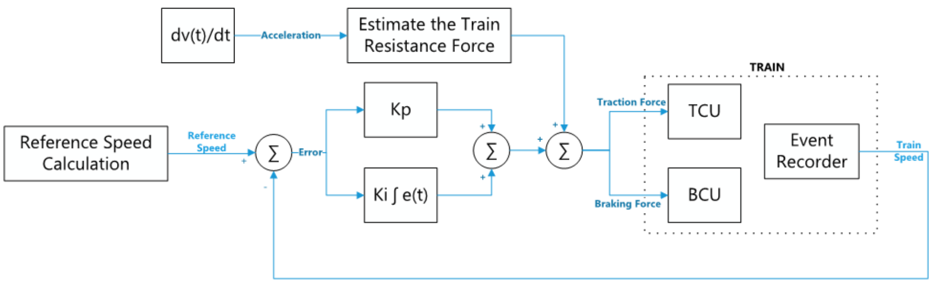

Figure 2: Block diagram of the ASC algorithm.

In order to estimate the total resistance force that the train is exposed to, the train acceleration must first be estimated. The ASC algorithm used the train speed to estimate the train acceleration. Afterwards, the total resistance force acting on the train is estimated by using the applied brake/traction forces and train acceleration as given in Equation (2).

$$F_{res} = F_{app} - mass_{train} * a \tag{2}$$

Prior to initiating testing on the train, it is essential to conduct integration tests in a laboratory setting to detect errors at an early stage. In this regard, establishing a test set-up for testing the ASC function in the laboratory is necessary. In the test setup indicated in Figure 3 and Figure 4, Train Control and Management System (TCMS) components including the CCU, Remote Input and Output Module (RIOM), Human Machine Interface (HMI), and Diagnostic Software, are physically present in the laboratory environment. Meanwhile, other train subsystems such as Brake Control Unit (BCU), Traction Control Unit (TCU), and Door Control Unit (DCU) are simulated using appropriate simulators. Based on the HIL methodology, this set-up includes various simulation devices and software for running scenario tests [8], with certain steps automated for swift and effective test executions.

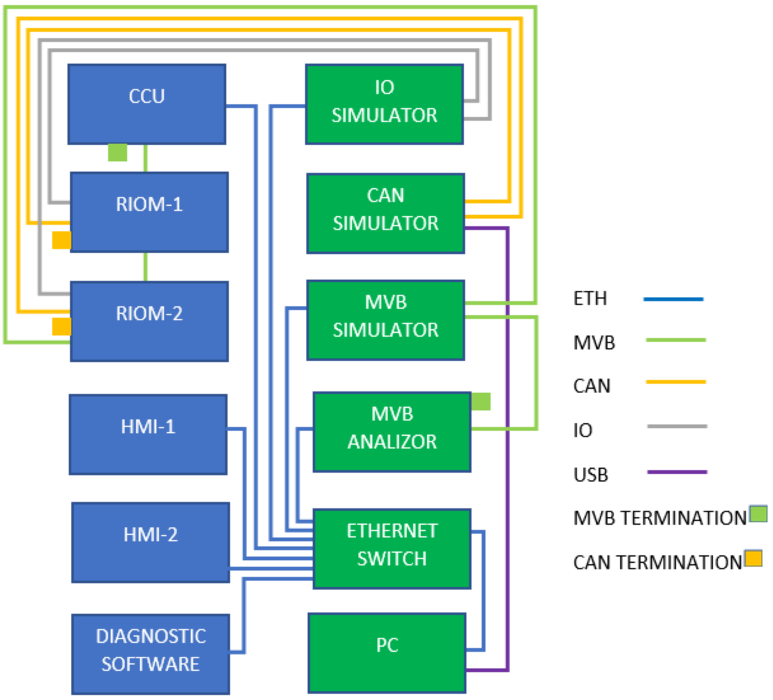

Figure 3: Block diagram of test set-up in laboratory.

Figure 4: View of test set-up in laboratory.

To initiate the ASC function, it is imperative to satisfy several preconditions. To satisfy these preconditions, various TCMS functions must be executed in the appropriate sequence. For instance, scenarios such as completing the train configuration properly, removing various major errors, and raising the pantograph to supply high voltage to the train are some of these preconditions. These scenarios should be verified to ensure that the train is ready for driving state as observed on the HMI or other monitoring tools. Subsequently, in order to activate the ASC function, the necessary inputs such as train mass, grade, ASC lever position, master controller position are sent to the MVB line from the test software interface as shown in Figure 5. CCU runs the ASC algorithm by receiving the inputs from the MVB line and sends a traction request to the TCU unit or a brake request to the BCU unit in order to provide the requested speed value within a certain range. The outputs are verified by checking HMI or test software.

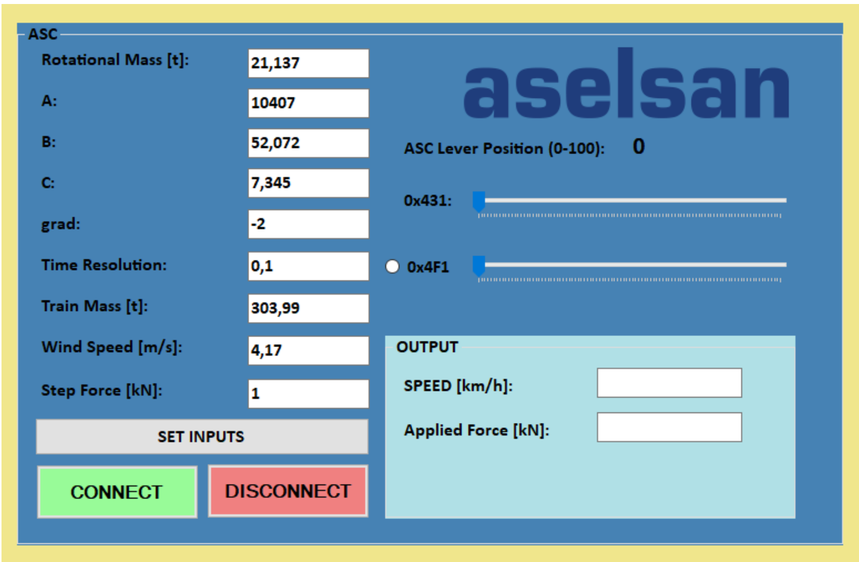

Figure 5: Test software for ASC function.

After the software is verified by laboratory tests, it is installed on the train and the necessary prerequisites to enable the transition to the ASC function are also verified on the train. In order to run on-train tests efficiently, a test set-up have to be established. In this set-up, unlike the situation in the laboratory, there is no need for a simulator, but various test tools are used to monitor and record the signals, as shown in Figure 6 and Figure 7.

Various test cases, such as where different cabins are active, different requested speed ranges, behaviour resulting from disruption of preconditions, failure cases of redundant signals, are tested comprehensively.

Revisions are made to the software as a result of errors or improvement suggestions detected during train tests. The new revision of the software is tested again in the laboratory and on the train, and this cycle continues until the software is validated.

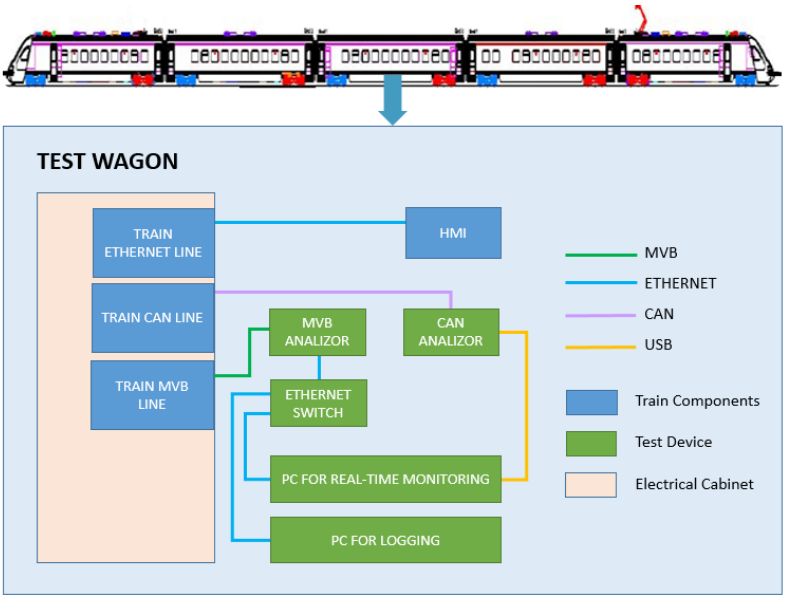

Figure 6: Diagram of test set-up on the train.

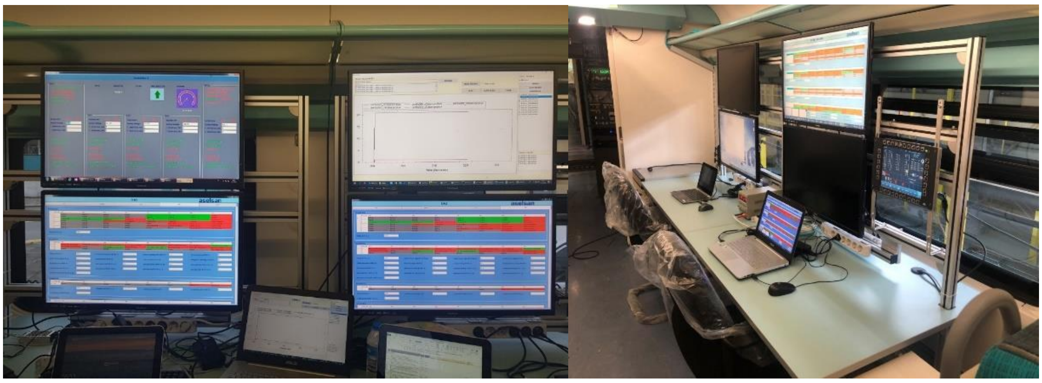

Figure 7: View of test set-up on the train.

3 Results

In this section, the results obtained from the experimental evaluations conducted on the ASC algorithm are presented. Three sets of data were collected and analysed, each corresponding to different testing environments: MATLAB Simulink (SIL) tests, HIL tests conducted in laboratory settings, and on-train field tests. The primary objective of these experiments was to assess the efficacy and performance consistency of the ASC algorithm across varying operational conditions.

Figure 8 shows the results from MATLAB Simulink SIL tests. The graph shows performance metrics for the ASC algorithm under simulated conditions. Through rigorous simulations, the ASC algorithm demonstrates robustness and effectiveness in keeping the desired speed control within acceptable tolerance limits.

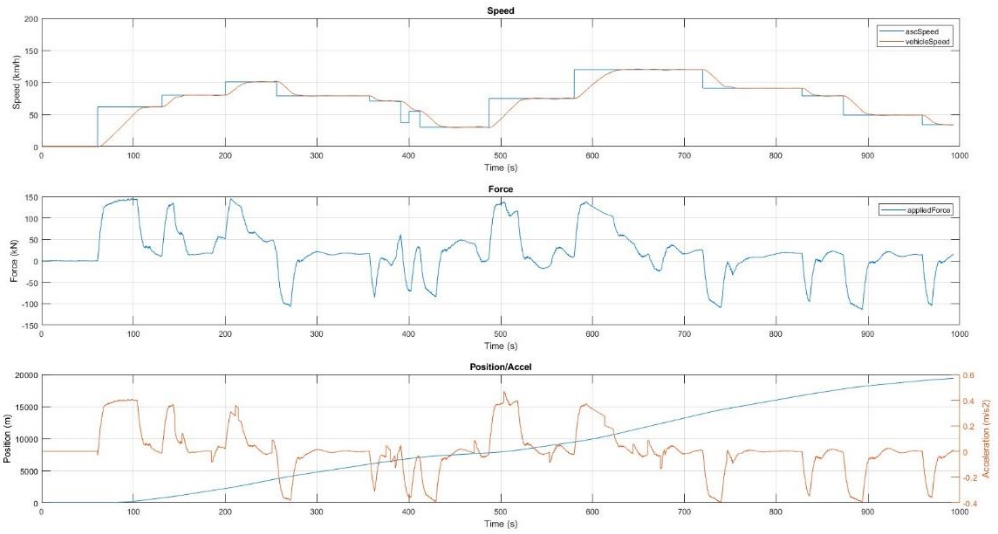

Figure 8: MATLAB Simulink SIL test results.

Figure 9 shows results from HIL tests performed in controlled laboratory environments. Similar to MATLAB Simulink SIL tests, the ASC algorithm performs well by effectively regulating the speed according to predefined parameters. The consistency observed in both simulated and laboratory-based experiments demonstrates improved reliability of the ASC algorithm.

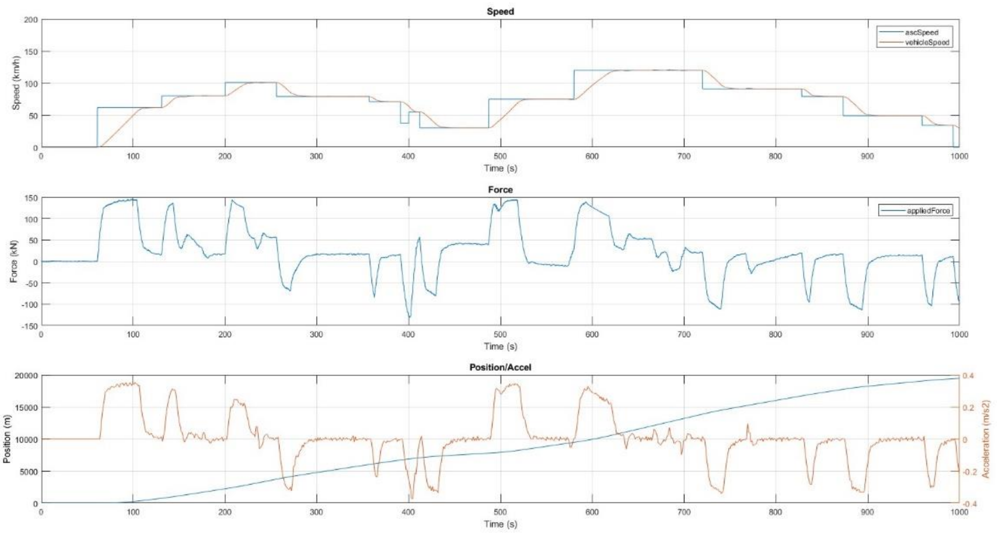

Figure 9: Laboratory HIL test results.

Figure 10 presents results from field tests on the train, reflecting real-world application of the ASC algorithm in operational scenarios. Despite the inherent complexities associated with real-time environments, the ASC algorithm demonstrates remarkable adaptability and effectiveness in maintaining rate control. The agreement between simulated, laboratory and train results also prove the robustness of the algorithm and its suitability for practical use.

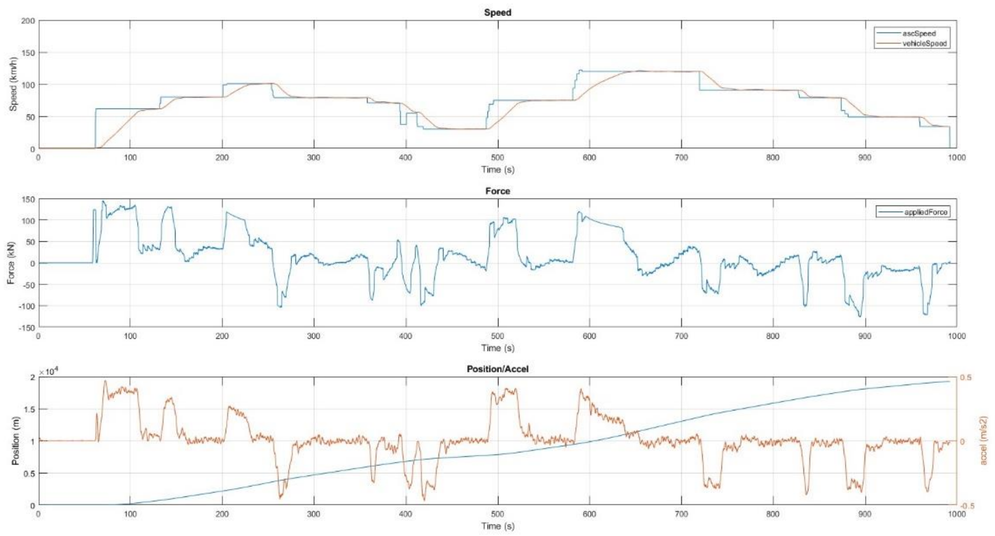

Figure 10: On-train test results.

It is noteworthy that all three sets of experiments yield results consistent with the expected results. The ASC algorithm confirms its effectiveness and reliability by consistently meeting predefined performance criteria in various test environments.

This consistency in results underscores the robust design of the algorithm and its suitability for integration into real-world systems.

4 Conclusions and Contributions

Designed specifically for EMU trains, the Automatic ASC algorithm, Simulink, has demonstrated consistent and robust performance in laboratory and train field tests. The methods used in this study were meticulously explained and applied sequentially, and a comprehensive design and testing of the effectiveness of the algorithm was carried out.

PI controller was used in the algorithm to keep the train speed constant according to the reference speed value. However, due to operational difficulties caused by the slope of the line, it turned out that the PI controller alone was insufficient to regulate the speed. To solve this problem, the total resistance force experienced by the train was estimated and dynamically included next to the PI output. This innovative approach increased the performance of the ASC algorithm, allowing more precise speed control even in difficult terrain conditions.

These findings confirm the reliability of the ASC algorithm and its suitability for integration into EMU train systems and contribute to the improvement of speed control functions in railway operations.

Acknowledgements

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