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Enhancing Fuel Efficiency and Emission Control in Diesel Locomotives through Auxiliary Power Units (APUs) in Neutral Conditions

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Abstract: This research investigates the imperative issue of fuel consumption and emissions in diesel locomotives during idle states, with a particular focus on the deployment of Auxiliary Power Units (APUs) in the neutral position (R-H). Diesel locomotives often exhibit a substantial fuel consumption rate, ranging from 23 to 25 litres per hour, during idling. This paper aims to elucidate the intricacies of optimising fuel consumption while concurrently addressing emission concerns without disrupting essential locomotive functions. In the quest for improved fuel efficiency and reduced emissions in locomotive operations, the utilisation of APUs in the neutral position (R-H) emerges as a pivotal point of investigation. APUs, which are auxiliary engines connected to the primary locomotive engine, play a significant role in achieving these objectives. The study delves into the health status and functionality of APUs during the locomotive's neutral state, examining their impact on fuel consumption and emissions. A comprehensive understanding of this aspect is crucial for developing effective strategies to enhance locomotive performance while curbing environmental impact. It is crucial to recognise that locomotives serve essential functions even when idling, such as supplying compressed air to maintain brake pipe integrity, powering the locomotive control system, and ensuring the charging of batteries. Consequently, locomotive operators often refrain from shutting down the primary diesel engine to conserve fuel. This research, through a meticulous analysis of APUs in the neutral position, endeavours to strike a balance between fuel conservation and the preservation of critical locomotive functions. By exploring the intricacies of APU utilisation, this study contributes to the ongoing efforts aimed at achieving sustainability and improved fuel economy within the railway industry.

Keywords: Loco idling; Auto engine shutdown (AES); Auxiliary power unit (APU).

Introduction

A locomotive/engine is used to pull the train. It is a common occurrence for locomotives to release harmful gases, including nitrogen oxide and particulate matter, during idle periods or when initiating operations. Interestingly, emissions tend to be more pronounced during locomotive idling compared to the emission levels observed during the starting phase. However, it is worth noting that the starting phase entails a longer duration for emissions to reach stabilised levels (Hedrick et al.,2008, Bryant et al.,1977)

The EMD 16-645-E engine exhibits higher pollutant emissions during idle conditions in contrast to the APU diesel engine when comparing the two (Fritz et al., 2005; Biess et al., 2003). Fuel cell locomotives generate no pollution, producing only water and heat as by-products. However, they exhibit lower efficiency

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when compared to other locomotive types, such as diesel locomotives (Arts et al., 2006).

Locomotive operators can potentially assess pollution levels using the Portable Emission Measurement System (PEMS), a recently introduced technology in Korea designed to analyse pollutant emissions from diesel locomotives. The PEMS is currently undergoing implementation in the country to ascertain pollutant characteristics (Kim et al., 2020).

Fuel cell locomotives produce no pollution, emitting only water and heat as by-products. However, they exhibit comparatively lower efficiency when just opposed to other locomotive types, such as diesel locomotives (Miller et al., 2006; Hess et al., 2008; Scott et al., 1993).

This paper offers an in-depth exploration of the operational dynamics of auxiliary power unit (APU) engines and their intricate relationship with the primary locomotive engines, shedding light on the issue of prolonged idle periods. Such idle periods are frequently encountered by trains, with a particular emphasis on freight trains, as they await signals or are stationed in outer areas and within station yards.

The gravity of this situation becomes evident when considering the statistics provided by the Indian railways which indicate a staggering 40% of fuel loss these attributable to waiting periods. To provide a clearer perspective, it is estimated that during just one hour of idleness, a locomotive engine consumes approximately 25 litres of fuel. In response to this substantial fuel wastage and environmental impact, locomotive pilots have adopted a proactive approach by implementing a complete shutdown role of the primary engine when confronted with these idle scenarios. This not only conserves fuel but also contributes to reducing emissions and overall operational costs in the railway industry. The study within this paper aims to delve further into the technical aspects of how APU engines function and there in mitigating the challenges posed by extended periods of locomotive inactivity.

Methodology

To overcome this situation there are two scenarios:

1. Shut down the main engine
2. Use of Auxiliary Power Unit (APU)

Approaching Above Scenario

Shut Down the Main Engine

In this specific scenario, locomotive pilots take the decisive step of completely shutting down the primary engine. However, a key concern that prevents them from doing so relates to potential leakages, which can result in a drop in brake pipe (BP) pressure within the train's formation, consisting of a series of interconnected wagons. Trains rely on air brake systems for the application and release of brakes, and it's imperative for the working pressure, known as BP pressure or brake pipe pressure, to be maintained at 5 kilograms per square centimetre (kg/cm^2).

When locomotives are in shutdown mode, their BP pressure is reduced to 0 kg/cm^2, effectively releasing the brakes. To restart the primary engine, it becomes necessary to not only recharge the BP pressure but also allocate additional time for charging locomotive batteries. This added time is essential for safety reasons, ensuring the train's systems are fully functional before resuming operations. Thus, meticulous attention to these specifications is crucial in preserving the integrity of the locomotive's functionality in such situations. So, this method is not applicable to fuel conservation.

Use of Auxiliary Power Unit (APU)

Using this APU, the micro-controller involved in the locomotive monitors the different parameters of the main engine and APU engine, such as the reverse handle position, the engine RPM, the BP pressure, the MR pressure, as well as the status of the batteries in the locomotive. To maintain the BP pressure, the micro-controller stops the main engine and starts the APU, which should require early re-cranking of the main engine in accordance with the locomotive's safe operating limits.

Working of Auxiliary Power Unit

The Auxiliary Power Unit (APU) is a key component in the locomotive system, comprising a small diesel engine, a compressor, and an alternator. It is integrated into the microcontroller-based control system of the locomotive. When the locomotive is idle for more than 10 minutes and the direction handle (R.H) is in a neutral position, the microcontroller alerts the loco pilot using a buzzer and a message. If the locomotive is idle, the reverser handle is neutral, and the brakes are applied, the microcontroller switches on the APU engine and shuts down the main engine to conserve fuel. For this engine changeover, the microcontroller continuously monitors critical parameters, including the status of the AES switch (ON), locomotive speed (zero), engine RPM (350 to 400), R.H position (neutral), brake cylinder pressure (greater than 1.5 kg/cm^2), engine water temperature (greater than 30°C), main reservoir pressure (above

7.5 kg/cm²), and average battery charging (less than 10 Amps). The APU consists of various components:

- Alternator: Converts mechanical energy into electrical energy in the form of alternating current.
- APU Battery: A 90AH battery is used to start and stop the diesel engine.
- APU Compressor: Maintains the main reservoir pressure above 7.5 kg/cm².
- APU Cranking Contactor (ACE): Energised to start the APU engine.
- APU Shutdown Contactor (ASC): Energised to stop the APU engine.
- APU Fuel Oil Float Switch (AFOFS): Monitors fuel oil levels in the tank.
- 12V Battery Charger: Used to start the APU engine.
- RPM Sensor: Measures APU engine speed.

- Before operating the APU, the current sensors show the battery charging status. If the charging current is less than 10 Amps, indicating partially charged batteries, the microcontroller allows APU operation. If the current is greater than 10 Amps, indicating moderately charged batteries, APU operation is not allowed.
- The APU engine runs while monitoring critical parameters. If any parameters deviate from safe limits, the microcontroller automatically switches to the main engine and shuts down the APU engine. If the loco pilot wants to move the locomotive while the APU is running, they need to shift the reverser handle. The microcontroller then starts the main engine, shutting down the APU.
- The APU operation cycle repeats as long as the idle conditions are met. The APU runs with low fuel consumption compared to the main engine, saving fuel wastage. The reverse handle can also control the APU. Additionally, there's a 16×2 LCD (liquid crystal display) used for displaying information, and an infrared obstacle sensor module that detects obstacles in front of it based on reflected infrared energy.

The ATMEGA328P microcontroller, a high-performance 8-bit controller based on AVR RISC

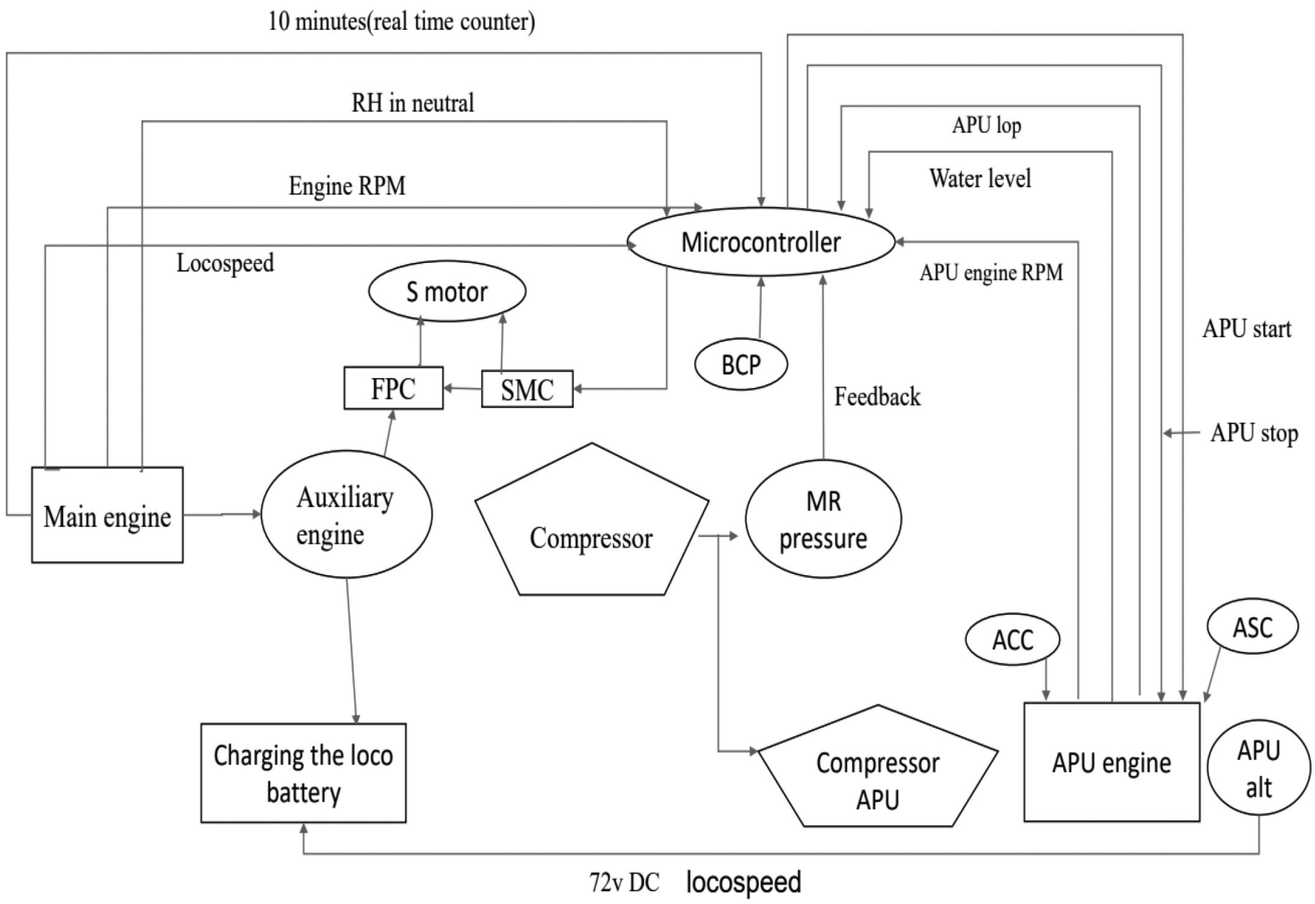

Figure 1: Block diagram of auxiliary power unit.

architecture, is used to control the APU's functions. It's programmed using an integrated development environment (IDE) and interacts with various components of the APU system.

Block Diagram of Auxiliary Power Unit

To comprehend the operation of the Auxiliary Power Unit (APU), we refer to the provided block diagram as shown in Figure 1. During periods when the locomotive is in an idle state, the primary engine remains inactive, and the auxiliary engine takes over to perform its role as a compact engine. This auxiliary engine functions in a manner that emulates the main engine's operations while consuming a reduced amount of fuel.

During the transitional phase from activating the auxiliary engine to deactivating the main engine, certain indicators of the locomotive's health become apparent. These indicators include parameters such as loco speed (locomotive speed), engine rpm (revolutions per minute), and the status of the reverser handle (RH) being in neutral.

These parameters are fed to a microcontroller, which in turn generates signals directed towards the APU engine, facilitating its initiation. As a result of this interaction, the APU engine comes to life. In scenarios where the locomotive requires a start-up, the microcontroller once again issues specific commands to the APU engine. This action leads to the cessation of the APU engine's operation, allowing for the resumption of the main engine's function with minimal time delay.

Block Diagram of Reverse Handle

Reverse handling is one of the prerequisites for operating an APU, as was previously stated. Figure 2 depicts the reverse handling block diagram. Attach the sensor module's VCC to the Arduino board's VCC. Attach the Sensor Module's GND to the Arduino Board's GND. Attach pin 7 of the Arduino Board to the sensor module's output pin. The LED will turn on when the obstacle avoidance sensor finds an impediment. If not, it will not function.

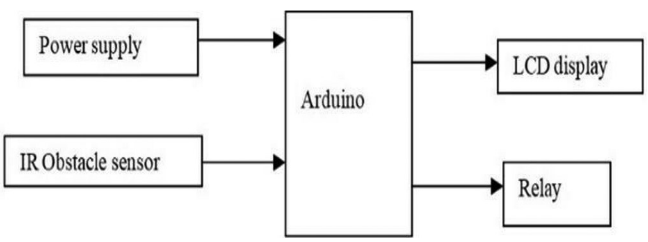

Figure 2: Block diagram of reverse handle.

ATMEGA328 is used similarly to any other controller. All there is to do is programming. The controller simply executes the program provided by us at any instant. As said, first we need to program the controller and that is done by writing the appropriate program file in the ATMEGA328P FLASH memory. After dumping this program code, the controller executes this code and provides an appropriate response. Figure 3 represents the pin diagram of ATMEGA328p.

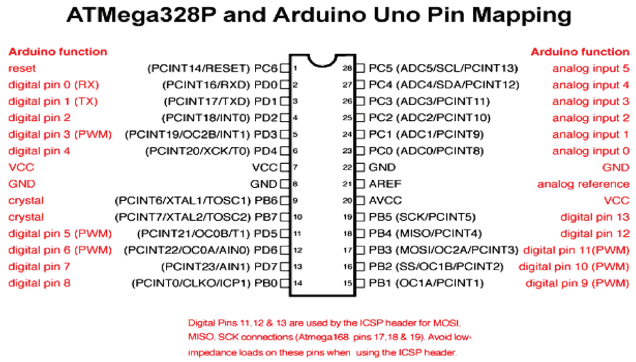

Figure 3: Pin diagram of ATMEGA328p.

Prototype of Auxiliary Power Unit in Diesel Locomotives

Figure 4 shows the basic construction of the RH neutral position. This prototype works as a part of the basic structure of the Auxiliary Power Unit in Diesel Locomotives.

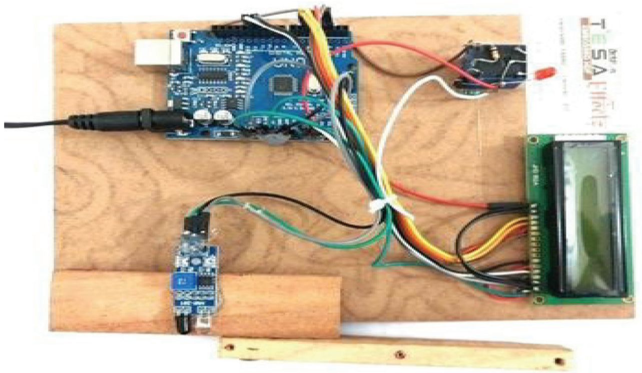

Figure 4: Prototype of auxiliary power unit in diesel locomotive.

This prototype contains:

1. ARDUINO UNO Board
2. LCD display
3. Obstacle sensor
4. Change over relay
5. Connecting wires

Figure 5 shows as long as the RH position is in a Forward or Reverse direction, the main engine is on. The message is displayed on an LCD display. The obstacle sensor switches from working mode to idle position when the RH position is forward or reverse. The obstacle sensor transmits the signal to the microcontroller. Based on the condition, the microcontroller passes a signal to the LCD to display the message.

Figure 6 shows the display message when the main engine is in on condition.

Figure 7 shows the RH position in neutral condition of the system.

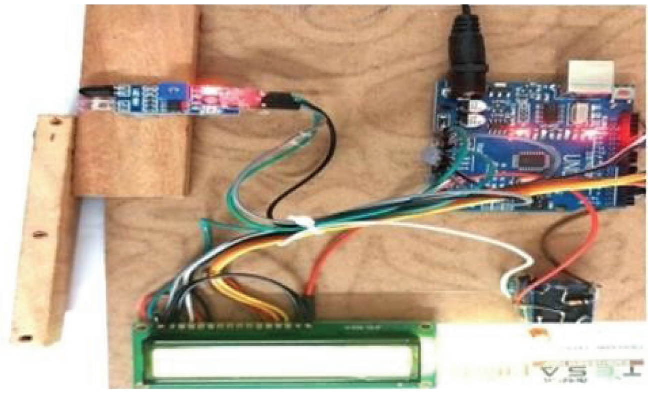

Figure 5: RH position in forward or reverse direction.

Figure 6: Displayed message.

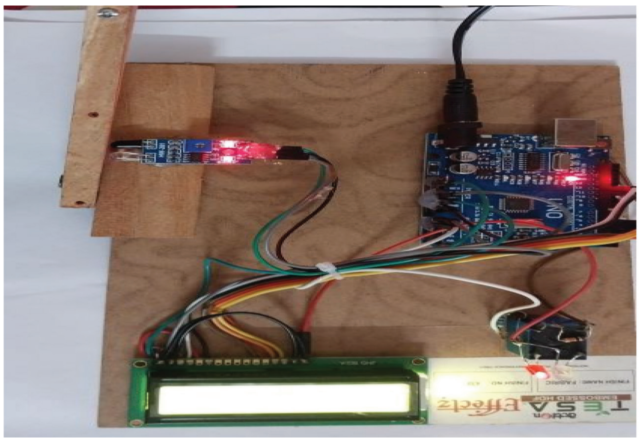

Figure 7: RH position in neutral condition.

Figure 8 shows the LCD display message when the RH is in a neutral position, and a countdown begins from 20 seconds to 1 second.

Figure 9 displays the message the message train is on. Here, the main engine will be off. Then the APU is in ON condition.

Figure 8: Displayed message with timer rolls from 20 sec to 1 sec.

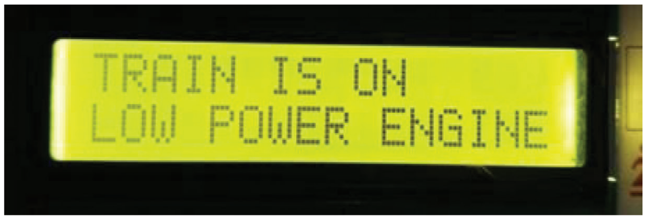

Figure 9: Displays message.

Conclusion

The average consumption of diesel in diesel locomotives is nearly 23 to 25 litres per hour when the train is idle. There is a need to reduce the amount of fuel wasted in locomotives. It is possible to reduce the fuel consumption with an Auxiliary Power Unit [APU] linked to the main engine by as much as 22 to 23 litres while still maintaining the same functionality by using an APU. As the APU engine idles, it performs the same as the main engine. The above prototype is used with one health condition (reverse handling neutral) and fuel conservation has been demonstrated.

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