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Design and Implementation of Electronic Controller for Optimal Functioning of Vacuum Toilets in Railway Passenger Transportation

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Abstract:- Vacuum toilet systems are used in most of the railway vehicles which manufactured for passenger transportation. The main purposes of using these systems are to suppress bad smells that may originate from toilets used in railway vehicles and to prevent diseases that may arise from toilet waste by improving hygiene conditions. In terms of environmental effects, it prevents causing corrosion on the rails because of human-made wastes and harms the environment by polluting water resources. In addition to these reasons, the vacuum toilet system saves 75-80% water in each wash cycle compared to a standard toilet. This study aims to design an electronic controller to be used in the vacuum toilet systems of passenger railway vehicles, which is cost-effective and can be easily adapted to different types of vacuum toilet systems.

To design the controller, the systems used in railway vehicles were examined and the design parameters such as programming language and processor type to be used, electrical interface, the functions to be executed by the controller, the number of input-output signals, cost, etc., were defined. Afterward, the designed prototype controller was produced and on-desk/on-board tests were carried out.

As a result of the study, a special electronic controller is developed for vacuum toilets systems used in passenger coaches and diesel multiple units operated for passenger transportation in Turkey, produced at an affordable cost and started to be used actively.

The produced controller will be able to be used in different types and models of vacuum toilet systems which are used in railway vehicles used for passenger transportation, by adding or removing some functions deemed necessary on software.

Keywords:- *Railway, Passenger Coaches, Vacuum Toilet System, Water Saving, Environmental Protection.*

I. INTRODUCTION

A system known as a hopper toilet was being used in traditional railways vehicles to dispose of waste -produced from toilets- from the trains [1]. In this system, the waste is left on a rail or more frequently onto the ground close to the rail. This system works with methods such as draining directly from a hole at the lower base of the train or made by a washing process. This system is also called a direct drain toilet or flush toilet. In many countries throughout the world, these toilet types are especially used in old railway vehicles [2]. Their main disadvantages are that the toilets are not hygienic, do not provide sufficient comfort for passengers, and have dangerous consequences for both health and the environment. The waste left on rails or roads pollutes the railways and has the risk of polluting underground water resources. To avoid these negative impacts, special methods are developed for these types of toilet systems not to drain waste in passenger stations. One of them is to keep the toilet cabins locked when the train arrives at the station. The other one is to manually close the end of the toilet system's drain with the help of special equipment [3].

The first improvement was designed for traditional hopper toilet systems in the United States of America in 1915. This system was working with the principle of collecting waste produced from toilets into a tank and disposing of the waste by energizing a solenoid valve which is in front of the waste tank when the train reaches a speed of 40 miles per hour [4]. These types of toilets were used until 1995 in the United Kingdom [5][6]. Since the early 2000s, the railway sector has also started to use vacuum toilet systems like the ones used in airline vehicles and these systems have substantially become widespread [7].

Unlike traditional toilet systems, vacuum toilet system which is controlled by the command of electro-pneumatic valves and works with pressurized air and water source is used in the railway sector for providing passengers' comfort and hygiene, to prevent environmental pollution by collecting toilet waste in special tanks and it provides a considerable extent water saving unlike traditional toilets [8][9]. The vacuum toilet system needs 3 main resources. These are electrical supply, pressurized air source, and clean water source. The need for a vacuum toilet system in the railway sector has emerged from the comfort and hygiene desires of

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passengers using railway transportation, the widespread use of passenger railway vehicles arranging long distances, and longtime traveling [10][11].

Nowadays, 3 types of vacuum toilet systems are used in railway vehicles which are being used in Turkey [12][13][14]. These are PRM (persons with reduced mobility) type designed for handicapped passengers, European-style toilets, and squatting toilet-type systems. Equipment that is high-cost and mostly imported, is used in vacuum toilet systems. Although in recent years, vacuum toilet systems designed and produced by Turkey-originated firms have been used in some of the railway vehicles, the indigenousness rate of the used equipment has remained low and has failed to reach the desired levels in the process until now. Besides, regardless of being domestic production or imported, these systems have high costs, and this poses a great financial burden to the institutions which operate railways (Turkish State Railways Transport Inc.) and produce railway vehicles (Turkey Rail Vehicle Industry Co.).

The controller which was designed within the scope of this study may be used in vacuum toilet systems in passenger coaches and diesel multiple units used in Turkey for passenger transport [15][16]. In the study, it is aimed to increase the indigenousness rate of the equipment of vacuum toilet systems while minimizing the cost by designing and producing vacuum toilet systems within the scope of the institution which manufactures railway vehicles. Thanks to the designed controller, a vacuum toilet system that has a low cost and whose all-design parameters will be determined by the institution that produces railway vehicles, may be produced if it is necessary.

When it is considered in terms of the cost of the controller, which is only one of the many parts of the vacuum toilet system, it is calculated that the designed controller costs 80% less than the controllers used in existing systems. With the start of widespread use of the designed controller, the financial burden occurring because of the spare parts needed to be kept or provided for the maintenance/operation of different types and models of vacuum toilet systems will decrease. In addition, the labor time required for maintenance/operating services will be saved.

II. MATERIAL AND METHOD

A. Working Principles and Functions

Some preliminary checks are required to get the vacuum toilet system ready for operation. The system needs pressurized air at 5 bar and a clean water supply. The system gets the required air supply with the help of an air compressor mounted on the railway vehicle. The air compressor produces pressurized air at 10 bar [17]. There is a pneumatic diagram drawn in a software platform called Fluidsim which belongs to the Festo firm in Figure 1 and pressurized air is available at the inlet side of the air filter called T01 [18]. The air passes through the check valve called T04 (provides one-way transmission) and comes to the pressure limiting valve called T05. This valve is used because it is aimed to use the air efficiently in the railway vehicle and it only allows air passage when the air value comes up 5 bar at the inlet. The air which is supplied to the system may be opened or closed with the help of T03 and T06 isolation valves. The pressurized air which is passed through T03 and T06 valves is decreased to 5 bar with the help of a pressure regulator [19]. The knowledge of whether 5 bar pressurized air is available in the system is transmitted to the controller with the help of a pressure switch [20].

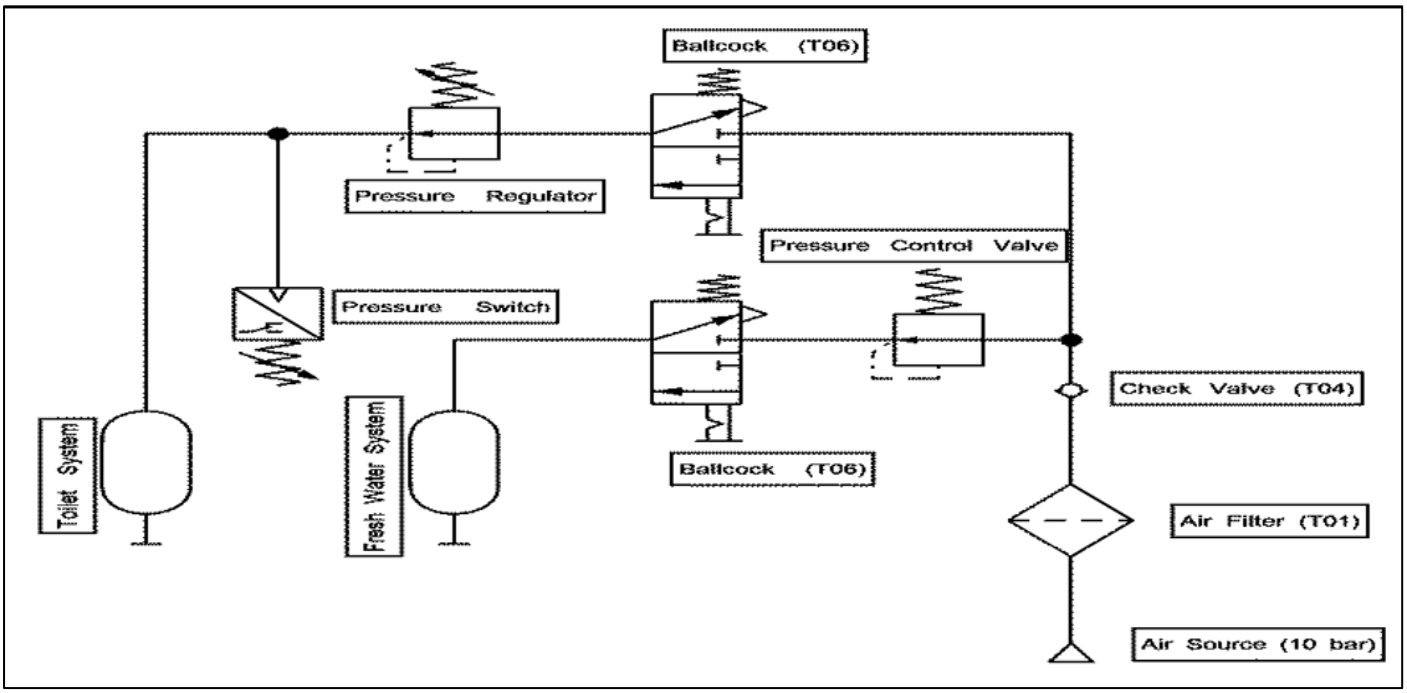

Fig 1: Vacuum Toilet System's Pneumatic Connection Diagram

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In the vacuum toilet system, 6 level sensors are used in total to give information to the controller by measuring the levels in clean water and waste water tanks [21]. The clean water sensors are located in the way to determine whether the clean water tank is filled with water at the levels of 10%, %30, or 90 % [22]. The information received from the sensors is electrically transmitted to the controller. At the same time, if the controller does not receive information from sensors that are measuring the 30% and 90% levels, it reports that there is little water left in the clean water tank. If no signal arrives from the sensor measuring the 10% level, the controller reports that there is not any clean water left and it stops the water-related functions of the vacuum toilet system and it passes to the out-of-service position. It informs authorized vehicle personnel by transmitting the info to the train computer (Train Monitoring System – TMS) that there is little clean water and the vacuum toilet system is out of service. 3 level sensors are measuring the levels of 30%, 75%, and 90% in the waste tank. The controller warns the user by passing into an error state when the waste tank is full at 90% or over and it stops the related functions. Also, the controller transmits the data to the TMS that the waste tank is full and the vacuum toilet system is out of service [23].

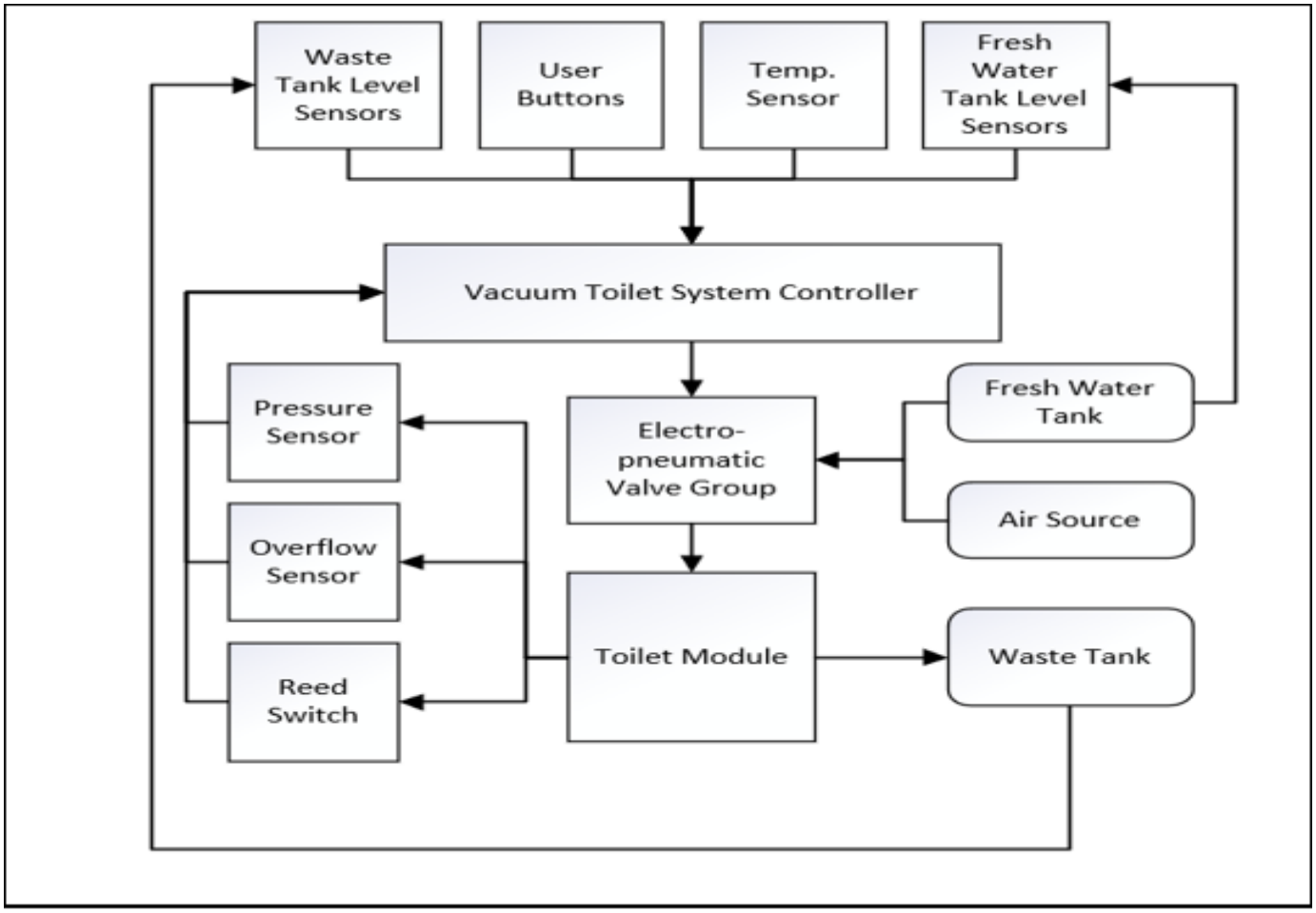

Fig 2: System Diagram

The controller of the vacuum toilet system proceeds to the next preliminary check when there is water and pressurized air. There is a pneumatic valve (Inlet valve) that does the opening/closing process of the connection between the upper reservoir of the mechanical unit and the intermediate tank. The position of this pneumatic valve (open/close position) is electrically transmitted to the controller via a magnetic sensor (reed switch) [24]. The pneumatic valve should be in the closed position when the vacuum toilet system does not carry out any functions. The controller waits to receive this info (closed position info) to pass the ready position. The controller passes into an error state by stopping related toilet functions in case the pneumatic valve is engorged at the open position or broken down or the sensor has malfunctioned. The next preliminary check after that step is that the analog data received from the pressure sensor is evaluated by the controller. The pressure sensor can produce output current between the range of 4-20 mA and may measure pressure between 0-5 bar. The sensor is mounted on the intermediate tank used between the upper reservoir and the waste tank, which is made of non-deformable special material and whose mechanical properties do not deteriorate within nominal pressure ranges. It transmits the pressure value from the intermediate tank to the controller. Finally, the vacuum toilet system gets into the ready position if the pressure value is between the predefined pressure limits [25].

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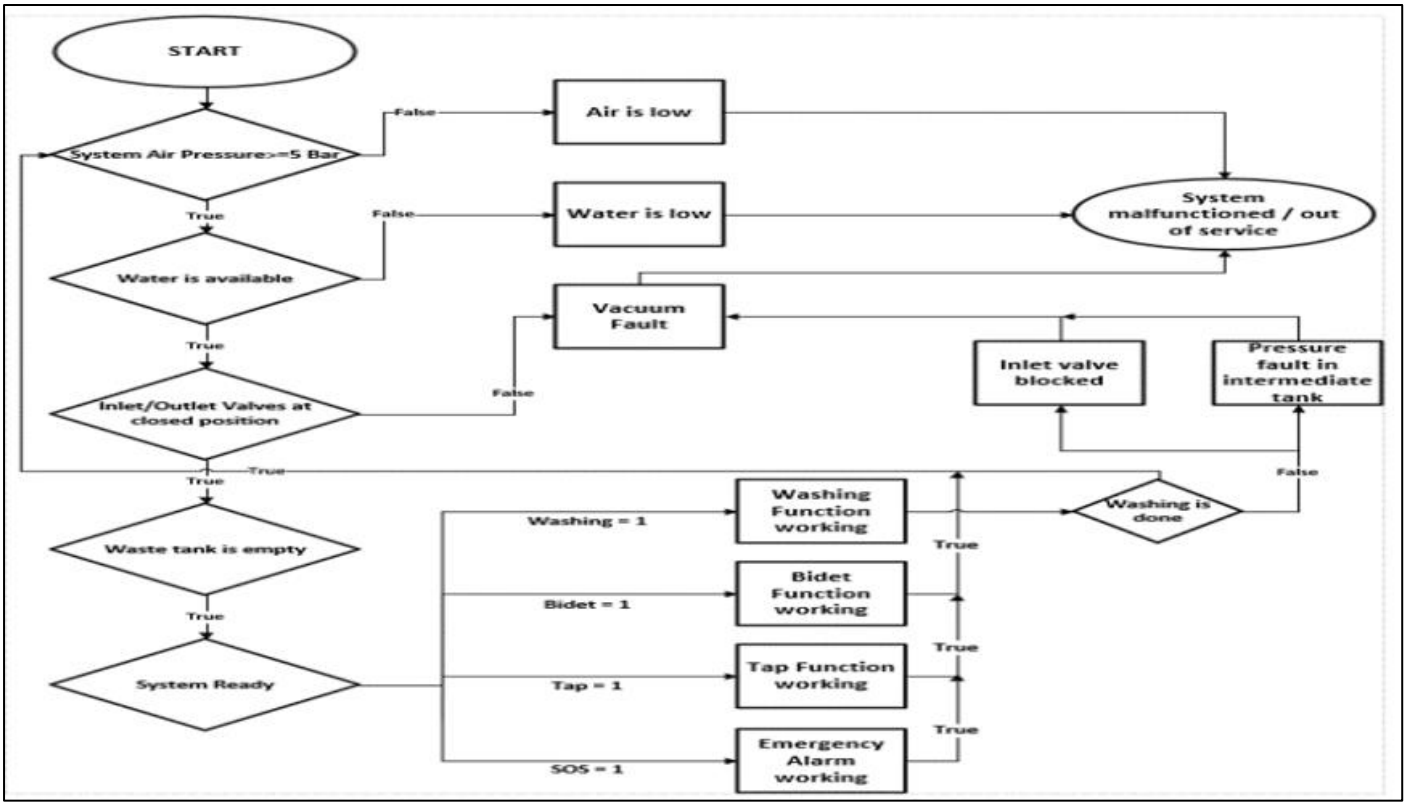

Fig 3: Flow Chart

The functions that a passenger can activate in the vacuum toilet system are the washing function, bidet function, tap function, and emergency case function. In addition to these functions, the functions that are operated by the controller which are independent of the passenger's request, are the anti-freezing function, overflow prevention function, back siphon/ service siphon function, and transmitting the diagnostic data related to toilet systems to the passengers, and vehicle personnel.

➢ *User-Activated Function*

- **Washing Function:** When the passenger presses the related button to use the washing function, two solenoid valves that spray water to the upper reservoir simultaneously start to work. The valves remain on for approximately 0.5 sec. according to the size of the nozzles used. After the upper reservoir is filled up with sufficient water, to vacuum the mass from the upper reservoir, the valve which is called as ejector valve and ejects the air from the intermediate tank to the outer environment is operated by the controller considering the time and pressure values. Within that period, whether the pressure in the intermediate tank is within the ideal value limits is monitored by the controller via the pressure transmitter which is connected to the intermediate tank. Lower and upper-pressure limits have been restricted by the controller to prevent damages from occurring in the intermediate tank. As soon as the sufficient vacuum effect is generated in the intermediate tank, the ejector valve gets de-energized and the line between the upper reservoir and intermediate tank is opened by energizing the inlet valve. After sufficient time passes, the upper reservoir is insulated from the intermediate tank by de-energizing the inlet valve. The inner pressure of the intermediate tank is raised to a higher-pressure level (approximately 1.5 bar/8 mA) than atmospheric pressure with the help of the pressure valve which is used for the pressurization process. When the desired pressure level is obtained, the outlet valve connects the intermediate tank to the waste tank and the draining process occurs. After the draining process finishes, the two solenoid valves (flush check and flush pressure valves) which spray water to the upper reservoir are re-energized. These solenoid valves are used to prevent operating without water and prevent emitting bad odors from the toilet cabin. It causes the washing function to be interrupted in case the inlet valve cannot be opened or closed during the washing function. The controller produces diagnostic data that the inlet valve is engorged. Moreover, vacuum error is produced by the controller if pressure levels that are defined for pressurization or vacuum effect processes are not reached at a particular time. The timing diagram of 6 pneumatic valves used actively in the washing function is given in Figure 4 which is captured via the logic analyzer [26].
- **Bidet Function:** After the passenger presses the related button to operate the bidet function, the selenoid valves which command the air and waterway of the bidet nozzle are energized by the controller along the determined time. Sufficient water flows from the bidet nozzle with the help of pressurized air.

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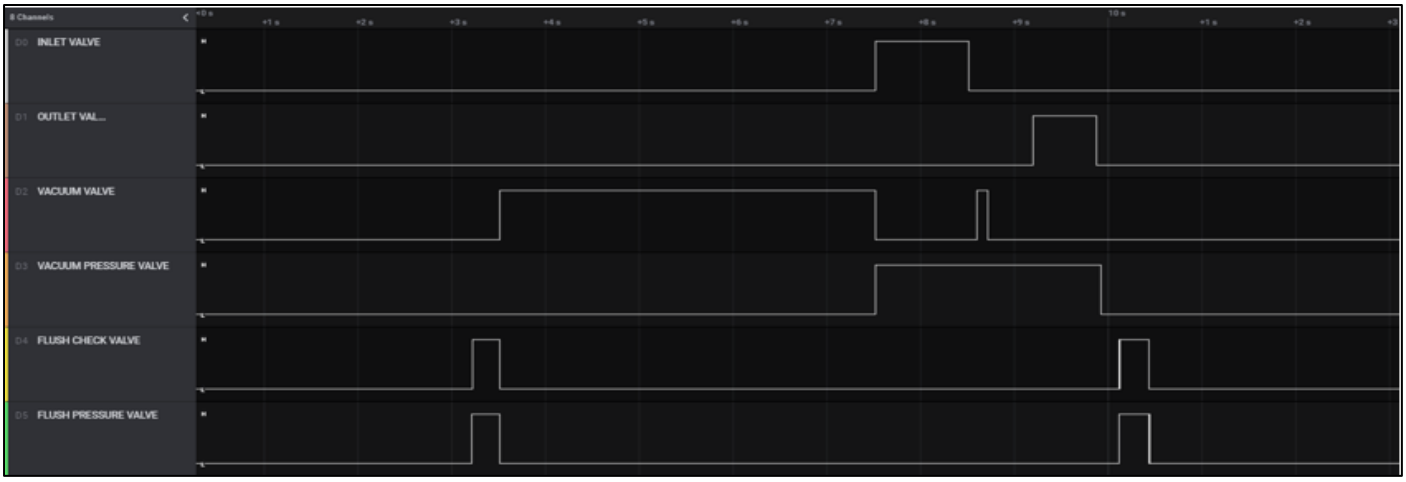

Fig 4: Timing Diagram of Washing Function (Logic Analyzer View)

- **Tap Function:** After the passenger presses the related button to activate the tap function, the valves commanding the air and waterway of the tap nozzle are energized by the controller at the determined time.
- **Emergency Case Function (SOS):** As soon as the passenger presses the emergency case button (SOS), a buzzer (audible warning device) produces a voice that can be heard from the passenger saloon area, and is energized by the controller. At the same time, the indicator which is located on the top of the toilet cabin changes color (green to red) showing the emergency case.

➢ *The Functions Carried Out by the Controller*

- **Antifreeze Function:** The vacuum toilet system's controller can operate a selenoid valve named drain valve (antifreeze valve) to protect the vehicle's mechanical equipment with the temperature data received from the temperature sensor which is mounted on the clean water tank of the vehicle. Because Turkey has a variety of operation/climate conditions, this function has been required. When the ambient temperature drops below 5° C, clean water is completely drained from the system by energizing the drain valve. Therefore, pecuniary damage is prevented which may be on the equipment of water installations and clean water tanks due to the freezing.
- **Sending The Diagnostic Data of the Vacuum Toilet System:** The vacuum toilet system's controller relays required information to the train machinist or maintenance personnel via the Train Monitoring System when the waste tank is full, the clean water level is low and the toilet is out of service. If there are these kinds of errors, it gives a visual warning to the passenger which shows the system is out of service.
- **Overflow Prevention Function:** A sensor (overflow sensor) that optically follows whether the maximum level is exceeded or not, is used on the upper reservoir of the vacuum toilet system. This sensor sends a signal to the controller as soon as the water accumulates up to the level where the sensor is located on the upper reservoir. When the signal arrives, the controller directs the waste in the upper reservoir to the waste tank by repeating the washing function 3 times without energizing the valves pumping water to the upper reservoir. At the end of the repeat cycles a certain amount of water is left in the upper reservoir. In Figure 5, the timing diagram of solenoid valves is given when the overflow prevention function is active [26].

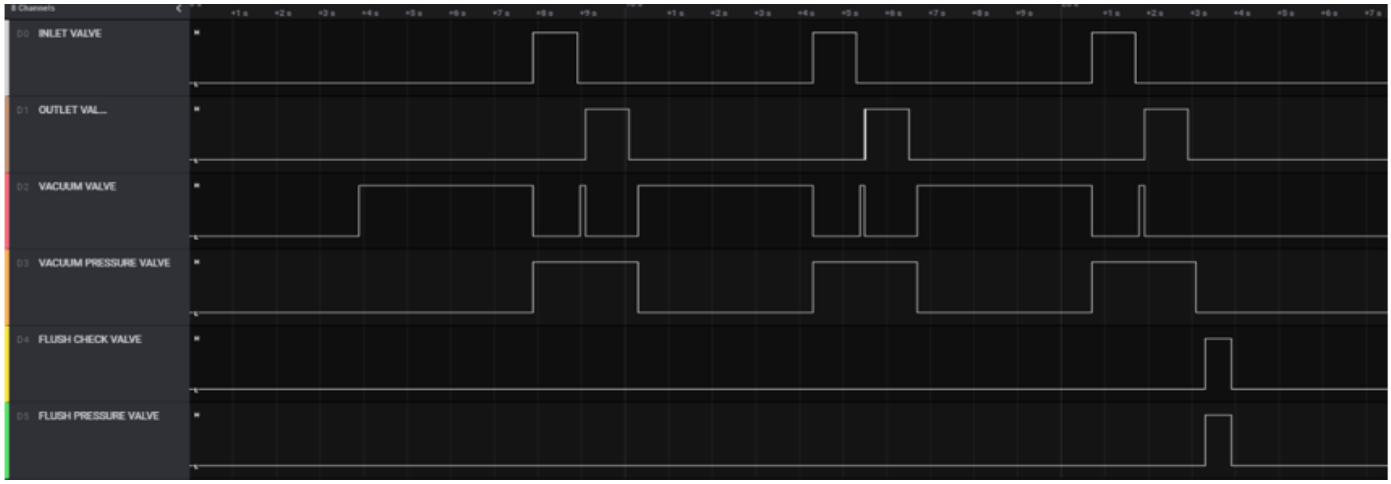

Fig 5: Timing Diagram of Overflow Function (Logic Analyzer View)

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- **Back Siphon and Service Siphon Function:** A vacuum toilet system that is used for passenger coaches often can be blocked due to the solid waste thrown into the toilet reservoir. In this case, the controller informs the maintenance personnel that the system is blocked. Two functions are submitted to the maintenance personnel to eliminate the blockage in the mechanical unit. The pressure value is increased by pumping air into the intermediate tank during the back siphon function and when the appropriate value has been reached, the material caused to blockage is thrown to the upper reservoir with the help of the pressured air driving force by energizing the inlet valve. The ejector valve which creates a vacuum effect in the intermediate tank is operated in service siphon function and when the required pressure value is obtained, the material caused to blockage is thrown to the intermediate tank by opening the inlet valve. These functions work with the help of two buttons.

B. System Architecture

For the design of the vacuum toilet system's electronic controller, an online circuit design platform called EasyEDA is selected. Also, the "PIC16F877" processor has been selected to be used as the processor [27][28]. MPLABX IDE as a code development environment and XC8 for code compilation processes have been used for the microcontroller which is selected for the vacuum toilet system controller [29][30]. 5 VDC voltage which is required for processor and peripheral units, is derived by regulating the 24 VDC voltage taken from the battery which is presented on the railway vehicle. The voltage regulation process is done with the circuit diagram in Figure 6. D25 diode is used to prevent inverse polarity voltage, and C34-C35-C30-C31-C29-C28 capacitors are used to filter undesired AC harmonics which might form at the railway vehicle. D27-D28 zener diodes (5.1V) are used to get protected from overvoltage which might occur at the regulator output.

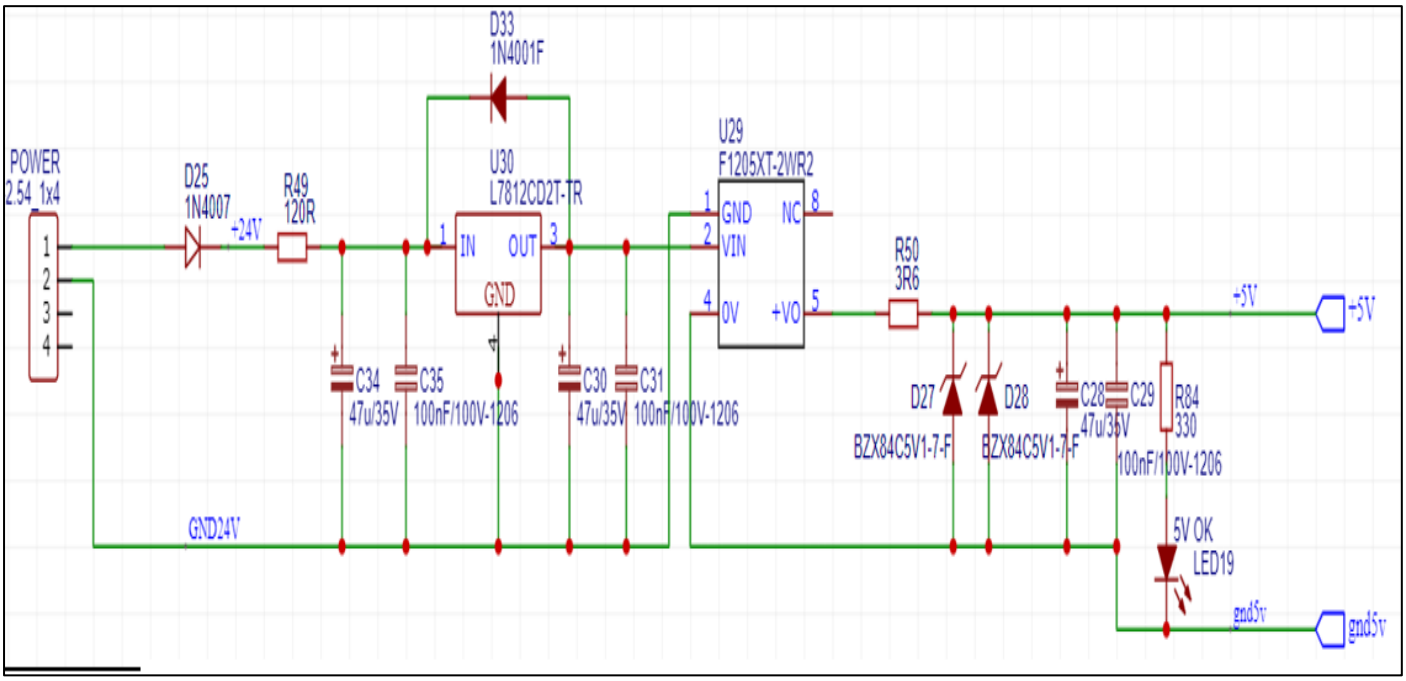

Fig 6: Voltage Regulation Circuit

➢ *Controller's Input/Output Ports*

Controller's input ports have been shown in Figure 7. The controller operates the vacuum toilet system by evaluating 14 input signals. 6 of them (which are within the range of I11 to I16 ports) are driven as logic 1/high (24VDC) when it is active and they are buttons that can be pressed by the passengers: These are washing, emergency, antifreeze manual activation, tap, antifreeze mode selection, and bidet buttons. The other 4 ports of the controller (which are within the range of I7 to I10 ports) are reserved to control the levels measured by level sensors; these are 10%-30% clean water tank levels and 75%-90% wastewater tank levels. When these ports are active, they are driven as logic 0/low (0 VDC) unlike the other digital ports. The remaining 4 ports are respectively reserved for the optic overflow sensor which is used for the overflow prevention function (I6), the pressure transmitter used to measure the pressure in the intermediate tank (I5), the reed sensor used to operate the washing function (I4), and lastly, "DS18B20" temperature sensor (I2-I3).

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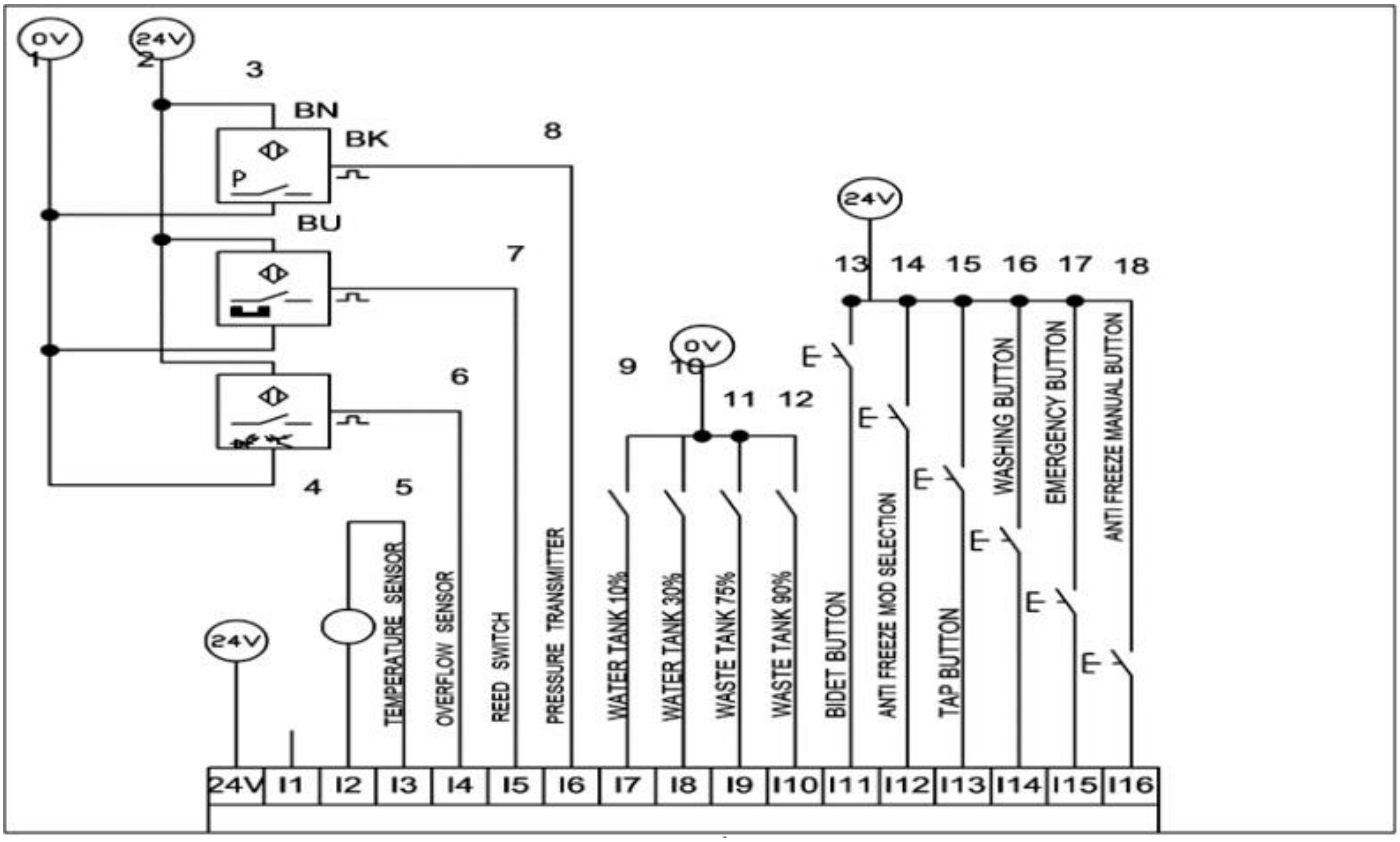

Fig 7: Controller's Input Ports

The circuit diagram has been shown which is used for digital signals coming to the controller in Figure 8. Because the input signal is created by supply voltage taken from the vehicle battery group, PC817 optocoupler IC (Integrated circuit) has been used which optically isolates the input and output to protect the processor input port [31]. The C1 and C13 capacitors have been used to filter distortionary AC components which may appear at the input or output of the IC. It is aimed to provide reverse voltage protection with the D4 diode and over-voltage protection with the D1 zener diode (33V) which are used in the design.

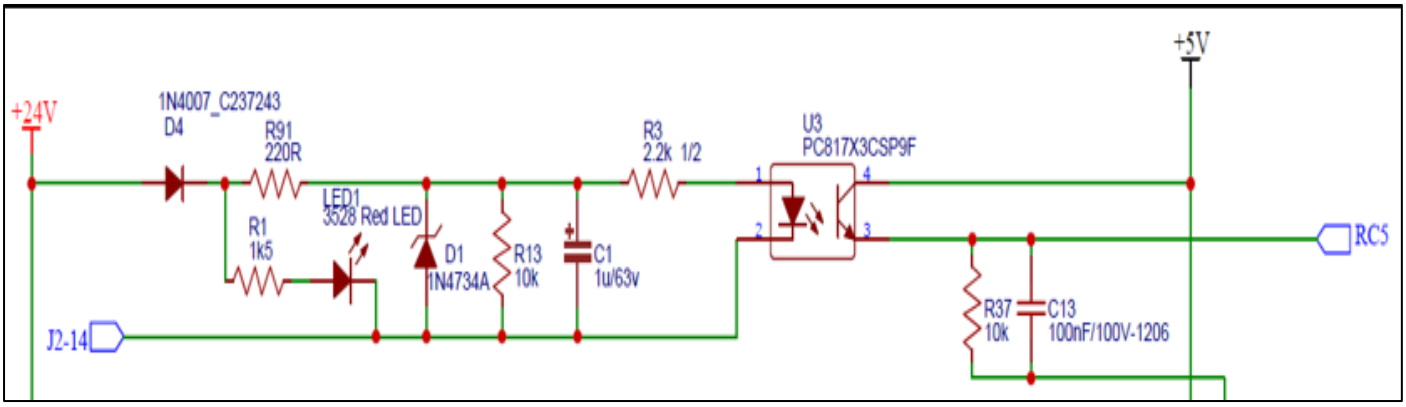

Fig 8: One of the Digital Input's Circuit Diagram

The "DS18B20" temperature sensor's connection interface has been shown in Figure 9-a. This sensor communicates with the PIC16F877 processor via the OneWire communication protocol [32]. "DS18B20" sensor transmits measured analog temperature data to the processor by converting it to 16-bit digital format. Some of the analog-digital conversion data has been presented as an example in Table 1. The temperature threshold value of 5° C is used to operate the antifreeze-prevention function in the vacuum toilet system. This function is carried out by the controller for all positive and negative temperature values 5° C or below [33].

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/IJISRT24SEP076

Table 1: DS18B20 Temperature Sensor's Analog-Digital Conversion Table

Temperature (°C)	Output (binary)	Output (Hex)
124°	0000 0111 1100 0000	07C0h
87°	0000 0101 0111 0000	0570h
+24,0625°	0000 0001 1000 0001	0181h
+11,125°	0000 0000 1011 0010	00B2h
+2,5°	0000 0000 0010 1000	0028h
0°	0000 0000 0000 0000	0000h
-2,5°	1111 1111 1101 1000	FFD8h
-11,125°	1111 1111 0100 1110	FF4Eh
-24,0625°	1111 1110 0111 1111	FE7Fh
-51°	1111 1100 1101 0000	FCD0h

The bit string and explanation which belongs to 16-bit data transmitted by the "DS18B20" temperature sensor have been shown in Table 2. When the temperature data is negative, the first 5 bits (most significant bits or sign bits) are '1', when the temperature data is positive, the value of these bits is '0'. In other words, for cases where the ambient temperature value is 5° or below, the data read by the processor will be smaller than the "0050h" or "Fxxxh" (negative values) value in hex format. In cases where negative temperature occurs, the values shown as 'x' are not taken into account about what they are by the processor [33].

Table 2: DS18B20 Register Format of the Temperature Data

BIT 7	***BIT 6***	***BIT 5***	***BIT 4***	***BIT 3***	***BIT 2***	***BIT 1***	***BIT 0***
2^3	2^2	2^1	2^0	2^-1	2^-2	2^-3	2^-4
BIT 15	***BIT 14***	***BIT 13***	***BIT 12***	***BIT 11***	*BIT 10*	*BIT 9*	*BIT 8*
Sign bits					2^6	2^5	2^4

The pressure transmitter connection interface has been shown in picture 9-b. Because the pressure transmitter produces a 4-20 mA analog output signal, current-voltage conversion (0-5 bar/4-20 mA -> 1-5V) is carried out via a 250-ohm shunt resistor. D29-D30 zener diodes (5.1V) are used to protect the processor's analog input port from overvoltages, and R100 is used for the current limitation. The "PIC16F877" processor has 10-bit ADC resolution [34][35]. Therefore, each step's size is calculated from the "maximum voltage/2^n" (n=number of bit resolution for adc module) equation. For the "PIC16F877" processor maximum voltage value is 5 V. In this case, the resolution of the adc module is found as 5/1024=0.004882813 (volt). Some of the analog-digital conversion values have been given in Table 3.

Table 3: "PIC16F877" ADC Module Conversion Values

ADC Values	0	50	100	200	250	370	400	600	650	800	1010	1024
Voltage Values (V)	0	0.24	0.49	0.98	1.22	1.81	1.95	2.93	3.17	3.91	4.93	5.00

Pressure parameters that are used in the vacuum toilet system's washing/overflow functions have been determined because of the system function tests. The minimal pressure that can be obtained in the intermediate tank is determined as 0.275 bar. The analog voltage value equivalent of this pressure value is 1.22 V, and the adc conversion value is 250. The maximum pressure that can be obtained in the intermediate tanks is similarly determined as 2.7125 bar. The analog voltage value equivalent of this pressure value is 3.17 V, and the adc conversion value is 650. The analog value corresponding to 1 bar pressure read in the normal operation of the system is 1.80 V and the digital value is 370.

In Equation 1, the calculation has been given which is used to convert (V_{adc}) the input voltage read at the analog-digital converter input of the processor to the pressure value (P_{adc}). (R_{sont}) value is 250 ohms, (I_{min}) value is 4 mA, (I_{max})value is 20 mA, (P_{min}) value is 0 bar and (P_{max}) value is 5 bar.

$$P_{adc} = \left(\left(\frac{V_{adc}}{R_{sont}} - I_{min} \right) \times \left(P_{max} - P_{min} \right) \right) \div \left(I_{max} - I_{min} \right) \quad (1)$$

The controller's output ports have been shown in picture 10-a. The controller manages the vacuum toilet system by controlling 11 output ports. Those outputs which are seen in the range of Q11-Q16 ports, carry out washing function and overflow prevention function. These 6 electro-pneumatic valves are shown which are operated by the controller the input valve, output valve, ejector valve, pressure valve, flush check valve, and flush pressure valve. These valves are 3/2 way and electrically activated, spring return electro-pneumatic valves [36]. The bidet valve seen at the output of Q5 is a spring return, the 3/2-way electro-pneumatic valve which is used to leave the water to the upper reservoir. Anti-freeze solenoid valve (drain valve) seen at the output of Q4 is a 3/2-way spring return electro-pneumatic valve that can be electrically activated and is used to prevent clean water tank and installation against freezing in cold weather conditions.

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The tap valve which is seen at the output of Q3 is a 3/2-way spring return electro-pneumatic valve that can be electrically activated for passengers to wash their body parts. The signal output which is seen in Q2 transmits to the Train Monitoring System that the clean water level is less than 10%. Finally, Q1 output is used to activate an audible warning device energized by the controller when the user presses the button in an emergency case.

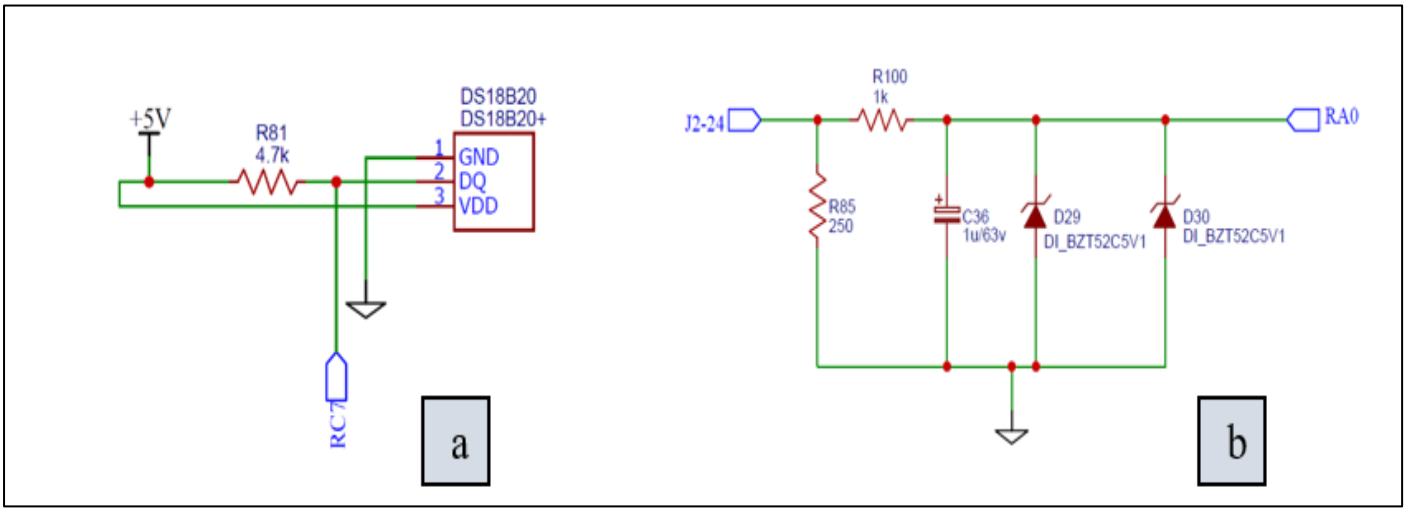

Fig 9a): Temperature Sensor Connection, b) Pressure Transmitter Connection

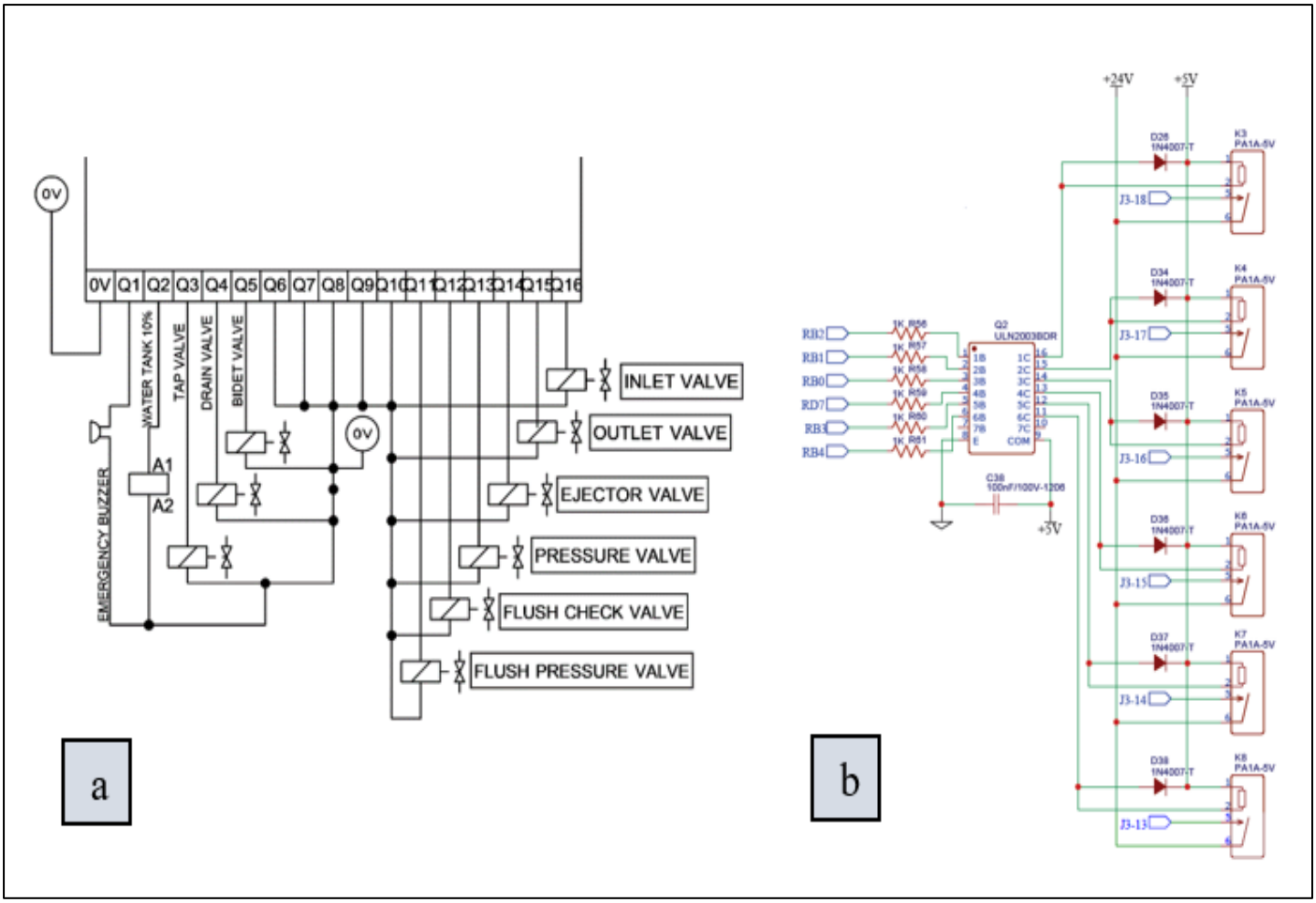

Fig 10a) Controller's Output Ports b) Washing/Overflow Protection Valves' Circuit Diagram

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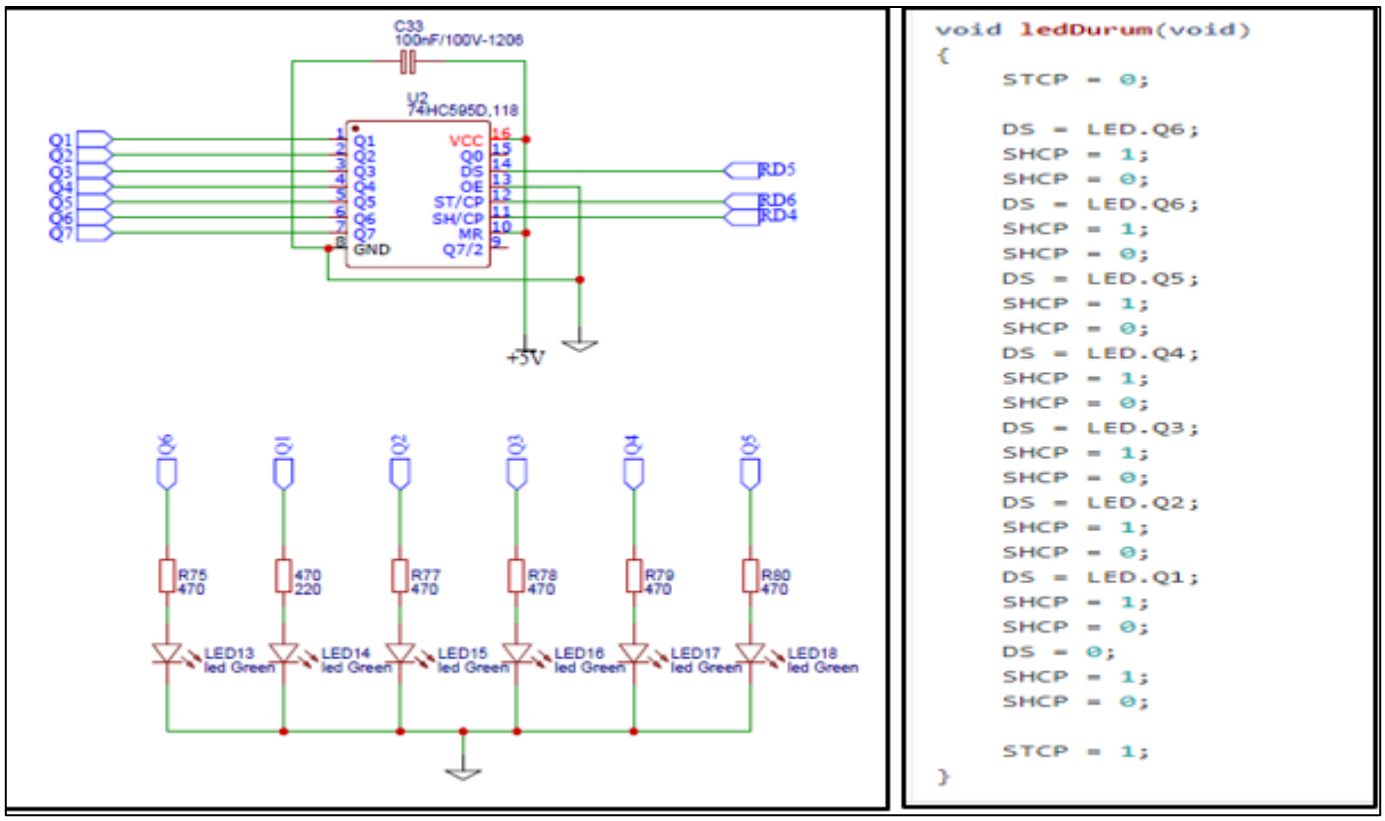

Fig 11: Diagnostic Leds' Circuit Diagram and Code Block

The circuit diagram which has been given in Figure 10-b shows the selenoid valves which the controller energizes while operating the washing/overflow function. The "ULN2003BDR" is a multi-purpose IC that is commonly used to drive equipment such as relays, lamps, etc., and can provide load current up to 500mA value for every single output port. It can be driven under variable voltage levels and it has darlington transistor arrays that can be parallelly connected to drive higher current loads [37].

The code block of the function called "*ledStatus"* and the circuit diagram which is used to transmit the diagnostic data of the vacuum toilet system to the passenger and maintenance personnel have been given in Figure 11. "74HC595D" is an 8-bit shift register IC. It sends the 8-bit serial input data to the 8-bit parallel output by shifting them one by one. It registers input data by beginning from the most significant bit of 8-bit data coming to the "DS" port by checking the voltage variation applied to the SH/CP port. It parallelly sends this data to the 8 outputs which are named Q1, Q2, …, and Q7/2 [38]. The purpose of using this IC is that only 3 processor ports are used to drive 6 (maximum 8 outputs can be driven) diagnostic LEDs. These diagnostic LEDs give information to the passenger/maintenance personnel such as whether the system is ready or not, whether the water level is sufficient or not, whether there is a vacuum system error or not, whether the system exceeds low or high-pressure levels, whether magnetic reed sensor works, whether the waste tank is full or not.

III. RESULTS

The project aims to develop a microcontroller-based controller which controls the vacuum toilet system which is used in railway vehicles. For this purpose, all electronic equipment that will be used in controller design has been determined, the controller has been designed in an online circuit drawing platform called EasyEDA. Because EasyEDA is an online platform, it has an electronic equipment library that is always developed by the users. Moreover, it has been preferred because it provides an opportunity to produce quick prototypes in contradistinction to commonly used platforms for electronic circuit design. Circuit diagrams are given in Figure 6-8-9-10-11 to exemplify the circuit structures belonging to the controller's design. "PIC16F877" microprocessor has been preferred to minimize the cost of controller equipment due to the requirements of the project such as the number of ports, its cost, and process capacity.

Netbeans-based MPLABX IDE platform which is used to develop microprocessor coding processes is an integrated development environment prepared for microprocessors which are designed according to Harvard, ARM, and MIPS architectures and produced as 8, 16, and 32-bit by the Microchip company. In the MPLABX IDE platform, a compiler called XC8 has been used which is developed for 8-bit microcontrollers to make error debugging and compiling in C language. This compiler (XC8) supports 8-bit PIC and AVR microcontrollers produced by Microchip firm. The compiler has ISO26262, IEC 61508, IEC 62304, and IEC 60730 functional security standards. XC8 compiler which has the manufacturer's full support has been used instead of 3rd

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party compilers such as MicroC, PICBasic, and PICC.

On-desk tests that are performed to develop the project have been carried out via an 8-channel logic analyzer in a computer environment. The most important two functions in the vacuum toilet system have been respectively shared: the logic analyzer view of the washing function in Figure 4 and the logic analyzer view of the overflow prevention function in Figure 5. The digital input signals coming to the controller are provided via some normally open switches (test switches), and analog input signals are provided via the power supply (variable voltage source in Figure 12).

The test equipment which is used for on-desk tests can be seen on the right side of Figure 12 and the controller whose on-desk tests have been carried out by this equipment was mounted to the vacuum toilet system's electric panel. With the completion of onboard tests, the prototype tests of the controller were completed. It has been made firm that the controller which has been designed by doing required adaptation processes and considering that vacuum toilet systems generally work in the same principle, can be used in railway vehicles which may have different vacuum toilet systems. Vacuum toilet system's electric panel which the controller used can be seen in Figure 13 on the left. The electric panel contains 17 connectors used in total for cables' interface coming from the vehicle side to the vacuum toilet system, 2 DC voltage supply distribution terminals, 13 relays, 2 anti-freeze function control buttons, 6 fuses, a room thermostat to control heating pack which is regulating vacuum toilet system cabin's temperature. Also, it has an isolation transformer which is used to supply 220V single-phase devices and the designed controller. On the right side of Figure 13, the mechanic toilet module of the vacuum toilet system used in the train set is shown.

Fig 12: Vacuum Toilet System's Controller and Testing Equipment

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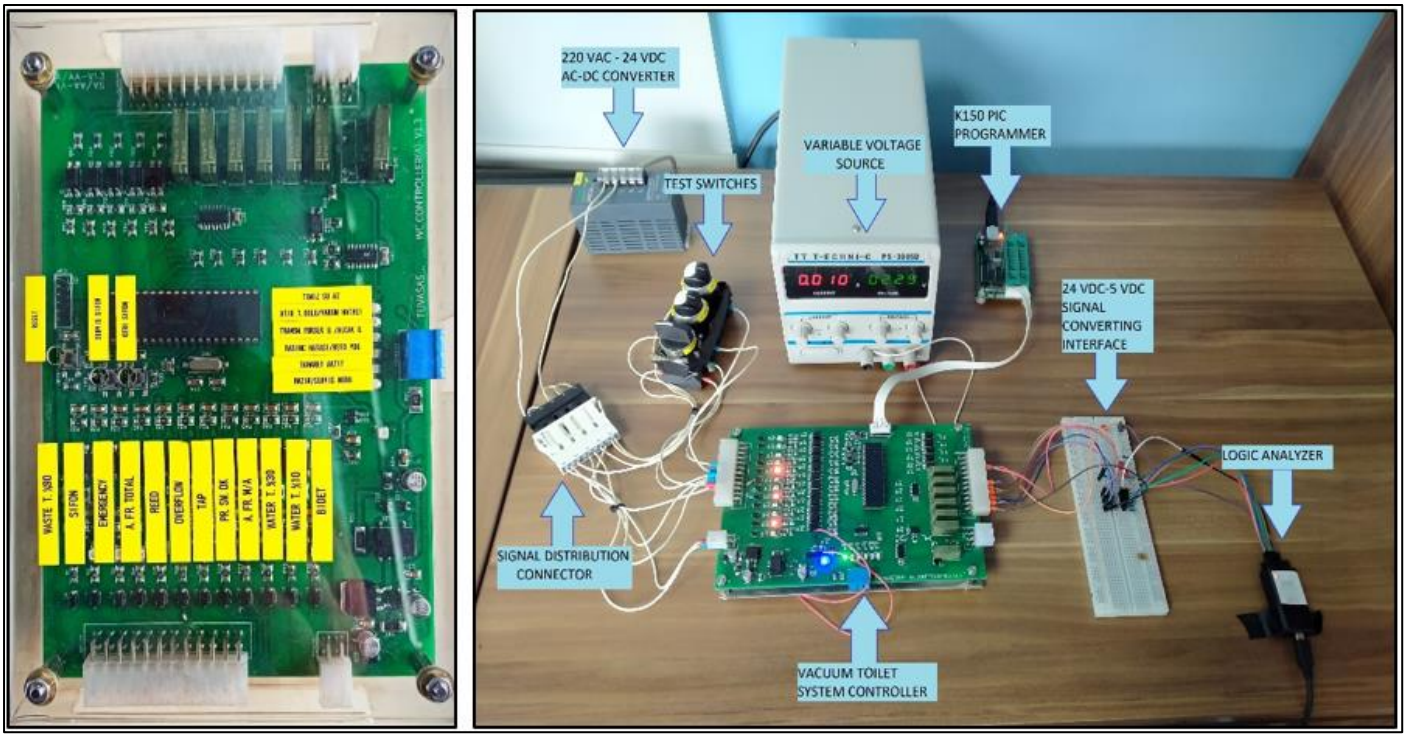

Fig 13: Vacuum Toilet System's Electric Panel and Toilet Bowl

IV. CONCLUSION

The need for a controller which will be used in the vacuum toilet system of railway vehicles used for passenger transportation has arisen because of the system's high cost. These systems are generally imported and therefore the cost of spare parts is expensive. In addition to this situation, vacuum toilet systems that are in use now are designed for specific projects therefore they cannot be integrated into the other projects of foundations and institutions manufacturing railway vehicles [39][40]. The designed controller can be used in more than one type of vacuum toilet system such as flush toilet, squatting toilet, and prm cabinet type [12][13][14].

The adaptation process, without requiring any hardware changes, for different types of toilets can be achieved by regulating some of the software functions. For instance, some of the railway vehicles used in Turkey do not have some equipment such as an overflow prevention sensor, reed sensor, and solenoid valve (drain valve) which is used for antifreeze prevention. The functions which will control this type of equipment can be programmed by the controller according to the type of vehicle by adding and removing when it is required in the software environment [41]. Moreover, convenient developments on the controller can be done by evaluating the requests and complaints of the personnel of the institution which carries out railway passenger transportation.

The disadvantages of the designed controller within the scope of the project are that it is visually simpler and its user interface is more complex than its equivalents, its diagnostic data is transmitted with separate cables for each signal instead of communication-based transmission to the Train Monitoring System. Also, in the meantime, there is no competent service personnel who will carry out after-sales/service processes in the institution that produces and operates vacuum toilet systems.

To eliminate the first of the disadvantages, the development which is planned in the project is to integrate a touchscreen graphic display (with a resolution of at least 320x240 pixels) onto the controller [42][43]. Owing to this, some of the diagnostic data transmitted to the user, error explanations, and some of the configuration parameters can be shown on the graphic interface display. The time values of some solenoid valves and some of the design parameters can be regulated with the help of this graphic interface in the vacuum toilet system. To eliminate the second disadvantage, necessary hardware is planned to be added to the controller for the commonly used communication protocols such as CanBUS and RS485 in railway vehicles [44][45]. When this hardware is added, it is predicted that the "PIC16F877" processor may not be used because of the insufficient port number, low processor speed and not having appropriate peripheral libraries. Therefore, the need to choose a more modern processor of a different type has emerged to be used in the new design. Because of this, it is planned that an appropriate type of "DSPIC33" processor will be used, which is also produced by Microchip company [46]. Lastly, necessary training manuals will be provided to the personnel who are working on the vacuum toilet system in the train operator and if it is necessary, training will be organized for related personnel at the points where the railway vehicles doing service.

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On-board tests, the last stage of this project, have been successfully carried out on the existing railway vehicle in use. This controller's current design will be frozen and mass production will be done for diesel train sets and passenger coaches which are used for passenger transportation in Turkey. In near future, it is planned to design a controller based on this design to be used in the vacuum toilet systems of electric train sets, which are starting to be produced in Turkey and will be put into passenger service in a few years [47].

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