Advancing Vehicle Safety: An Automated Emergency Air-Filling System for Tyre Maintenance

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Abstract: This study addresses the pressure issue of tyre-related accidents by proposing an emergency air-filling system for vehicles. The methodology involved the integration of mechanical and electrical components, including compressors, pressure sensors, microcontrollers, and pneumatic elements. The system operates by monitoring tyre pressure and automatically engaging a pneumatic cylinder to fill or release air as needed. Through synchronized gear mechanisms, the compressor and cylinder maintain optimal tyre pressure, thereby mitigating the risk of accidents caused by tyre punctures or blowouts. The results indicate that such a system offers a proactive solution to tyre maintenance issues, enhancing vehicle safety and driving performance. By preventing tyre-related accidents, this technology contributes to the advancement of automotive safety standards, aligning with the trajectory towards autonomous and intelligent transportation systems.

Keywords: Emergency Air Filling System, vehicle safety, tire puncture, tire pressure monitoring, Driver assistance systems and Automotive technology.

1. Introduction

In an era of rapid technological advancement, the concept of automobile safety has evolved from a mere consideration to an essential pillar of the automotive industry. Automobile safety stands as a cornerstone of the modern automotive industry, reflecting an unwavering commitment to protecting the lives of drivers, passengers, and pedestrians. As vehicles have become more integral to our daily lives, the imperative to mitigate risks and avert potential hazards has prompted automakers to engineer vehicles that act as protective shields on the road. From seatbelts and airbags to sophisticated collision avoidance systems, safety has become a defining aspect of automotive design. The realm of automobile safety has undergone profound transformations, becoming an inseparable facet of the modern automotive industry. The lack of robust automobile safety measures emerges as a significant being. These safety measures often do not centre their focus on the wheels of the vehicles. In contemporary times, a significant number of vehicles encounter tire punctures while contributor to the rising toll of accidents worldwide.

The absence or inadequacy of automobile safety measures reverberates across various dimensions, ultimately impacting the lives of drivers, passengers, pedestrians, and the overall fabric of society.

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Insufficient safety features in automobile, play a pivotal role in creating an environment conducive to accidents. Although safety regulations and standards have undoubtedly progressed, occurrences of accidents caused by insufficient automobile safety measures continue to endure. As society moves towards an era of autonomous vehicles and smart transportation, the exploration of inadequate automobile safety becomes even more pertinent. Vehicle accidents continue to pose a significant global challenge, affecting the lives of millions each year. Among the multitude of factors contributing to these incidents, tyre-related issues stand out as a persistent concern that warrants focused attention. The inconspicuous truth is that a considerable number of collisions result from inadequate vehicle maintenance and faulty tyres [1]. According to the National Highway Traffic Safety Administration, there are an average of almost 11,000 motor vehicle accidents related to tyres, resulting in around 200 fatalities annually [2]. The significance of tyres extends far beyond their functional purpose; they serve as the critical link between a vehicle and the road, directly impacting driving performance, vehicle stability, and overall road safety.

Tyres emerge as the utmost essential element of motor vehicles, evoking concerns owing to their exclusive interaction between the vehicle and the road.The abrupt failure or rupture of a vehicle's tyres can lead to a considerable deterioration in both vehicle stability and safety [3].Continual supervision and prompt maintenance of a vehicle's tyres are essential to uphold vehicle safety and optimize fuel efficiency [4]. The defective tyres increase the risk of a serious accident in inclement weather and adverse road conditions [5].Among the various tyre-related issues that exist, one of the most noticeable and significant is tyre puncture. The sudden puncture of a tyre in a vehicle can have several significant impacts, affecting both the vehicle's handling and the safety of its occupants. Some of the key impacts include loss of control, reduced brake performance, risk of accidents, rim damage, unstable driving, increased risk of rollover, potential tyre blowout, etc. Bulletproof vehicles, anti-lock braking systems (ABS), GPS tracking, and driver fatigue prevention are additional safety features found in automobiles. Despite the presence of numerous safety mechanisms, minor issues like underinflation and tyre punctures can greatly impact human well- traversing rough terrain and mountainous regions. In this circumstance, the act of inflating the tyres is carried out either at a mechanical workshop or by utilizing a portable compressor brought inside the vehicle. The presence of mechanical workshops is notably limited in these regions.

A considerable number of individuals rely on mechanical workshops for inflating their tyres. Conversely, those with limited access opt for portable compressors to alleviate the difficulties they face while traveling. One drawback is that it utilizes a considerable amount of space at the rear of the vehicle. Meanwhile, others spend valuable time waiting for human assistance in such situations [6]. This project finds a solution to overcome these drawbacks by integrating emergency air filling systems in vehicles, which have emerged as a vital tool to mitigate the risks associated with vehicle accidents. This mechanism aids in inflating the air within the vehicle's tyres, enabling them to sustain operation for a certain distance [9]. Consequently, it facilitates the driver's ability to reach a mechanic's workshop. Safety considerations are paramount when discussing emergency air-filling systems. While these systems provide a valuable solution for addressing immediate tyre pressure concerns. The introduction of emergency air filling systems in vehicles represents a significant stride toward enhancing vehicle safety and the challenges faced by tyre-related issues [12]. As the automotive industry continues to evolve, understanding the design, operation, and limitations of such systems becomes essential for drivers and enthusiasts alike [13]. Subsequent sections will delve into the technical intricacies of these systems, providing a deeper understanding of their functionalities and their role in shaping the future of vehicle safety [14].

2. Components of the system

A detailed breakdown of components is shown in Table 1, accompanied by their corresponding specifications, offering a comprehensive overview of the various elements that constitute the system.

Table 1. Components specifications

S.NO	Components	Specifications
1	Compressor	0.5 HP, piston type
2	Double acting cylinder	Stroke length=70mm, 0-10 bar
3	Two stroke Engine	2.61 Kw @ 5000 rpm
4	Pressure sensor module	9 Psi, 40mV full scale output
5	Microcontroller	8051
6	Gears	Cast iron
7	Solenoid valve	1 input 2 outputs, 24 DC power supply
8	Bearing	Inner bore 15mm

2.1.Mechanical Components

2.1.1.Spur Gear

The visual depiction of the spur gear is shown in Figure 1. The straight-toothed configuration of the spur gear facilitates a seamless and uninterrupted transfer of power to the adjacent gear. Both the gears are of equal dimensions and are linked to both the engine's crankshaft and a pneumatic cylinder. The gears are fabricated using stainless steel, known for its robust strength and balanced weight characteristics. An additional gear is linked to the output shaft of the compressor as a replacement for the pulley.

Fig. 1. Spur Gear

2.1.2. Piston type Compressor

In this system, a single-piston type compressor was used, as shown in Figure 2. This type of compressor was selected due to its demonstrated accuracy rate of 96%, and it has the capacity to be configured into different operational modes in alignment with various workload conditions. Compressors typically fall into three main categories: vane, screw, or piston designs. Essentially, the gas volume of the compressor is reduced by enhancing its pressure. Primarily, the user's need involves attaining a significantly elevated air pressure during the filling process. As a result, a compressor is employed to raise the air pressure accordingly. Compressors are well-suited for extensive applications necessitating air at elevated pressure levels. A single-stage positive displacement compressor comprises a piston enclosed within a cylinder. During its operation, a considerable amount of energy gets converted into heat, which can impact the precision of the system. To counteract this effect, air fins are integrated to dissipate the heat generated by metal components, ultimately resulting in an augmented requirement for input power. Because of this constraint, a smaller compressor requires an air-cooled setup, while a larger compressor requires a water cooled arrangement. The maximum capacity for a single-piston compressor is 150 psi. Exceeding this threshold can cause the compressor to deviate from its intended accuracy. Greater efficiency of the pump is attained by employing multiple cylinders in a compressor through a process known as staging [7].

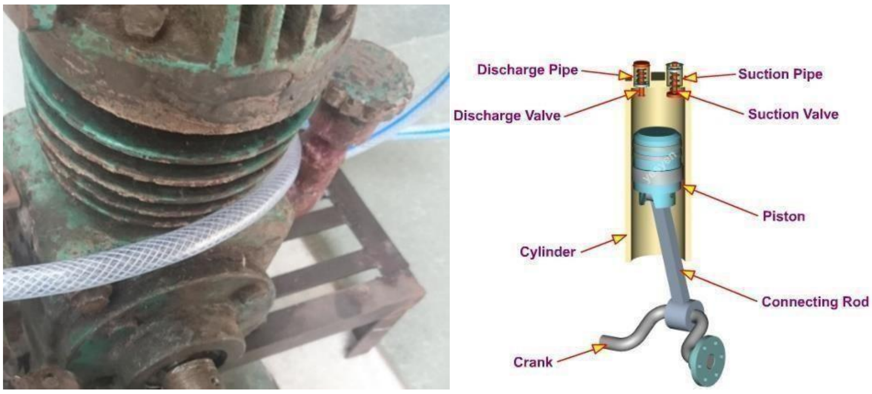

Fig. 2. Single-Piston Compressor

2.1.3. Bearing

The bearing serves as a mechanical element that permits relative motion between two elements, like the shaft and the housing, with minimal friction.The function of the bearing can be described as: The bearing provides smooth rotation of the axle with minimal frictional resistance. The bearing provides support to the shaft or axle, ensuring accurate positioning to facilitate energy transfer. As a consequence of braking, the force generated is transmitted to the frame or foundation through the axle or shaft.

Bearings are grouped into different classifications. Based on the friction and force direction, the load on the bearing is divided into two distinct types: radial bearings and thrust bearings.A radial bearing provides support for a load that is positioned perpendicular to the shaft's axis, whereas a thrust bearing enhances a load that acts parallel to the shaft's axis.The fundamental factor determining the ranking of bearings is the nature of the contact between the shaft and the bearing surface.Bearings are categorized into two primary groups based on the type of friction they experience: sliding contact bearings and roller contact bearings.Roller contact bearings are employed within this system, as shown in Figure 3.Roller contact bearings are alternatively referred to as antifriction bearings or commonly known as ball bearings.Rolling or spherical components like balls or rollers are introduced between surfaces experiencing relative motion.

In this bearing configuration, sliding friction is effectively substituted with rolling friction, leading to significantly improved bearing durability.

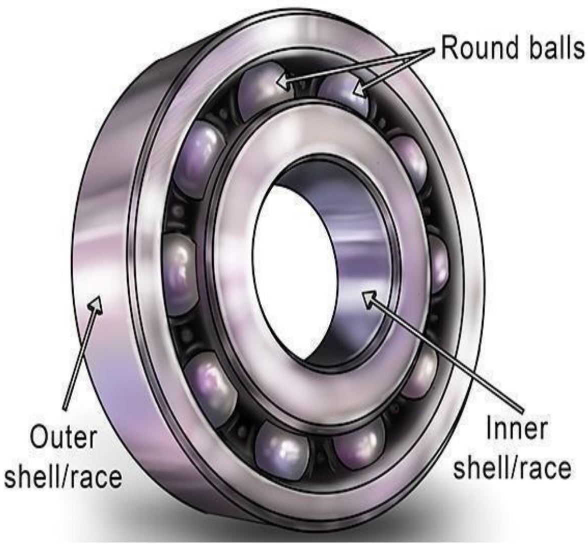

Fig. 3. Roller contact Bearing

2.1.4. Solid works Model

SolidWorks is a widely used computer-aided design (CAD) and computer-aided engineering (CAE) software application. SolidWorks is used to create 3D models and assemblies of products, perform simulations, and generate technical drawings.Figure 4 illustrates the 3D assembly of the components, showcasing their arrangement within the design.

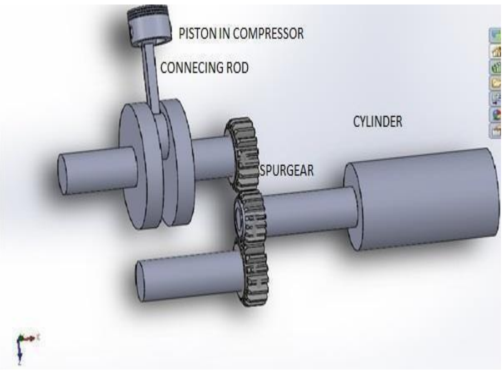

Fig. 4. Solid works model

2.2. Pneumatic Components

2.2.1. Double acting Cylinder

In this system, Double acting cylinder is used as shown in Figure 5. The double-acting cylinder is characterized by two distinct strokes: an outward movement called the outstroke, and an inward movement known as the instroke.The double-acting cylinder utilizes pressurized fluid cycles on either side of the piston, resulting in forces that extend and retract the piston rod. This method enables enhanced movement control and improves operational precision[8].

Fig. 5. Double acting Cylinder

2.2.2. Pneumatic Solenoid Valve

This system incorporates a pneumatic solenoid valve, as illustrated in Figure 6. In order to eliminate the necessity of human involvement in pneumatic circuits, a pneumatic solenoid valve can be employed. This pneumatic valve is activated by an electrical signal.It falls into the classification of both a two-port valve and a three-port valve. AMagnetic field is produced by passing the electric current. This current generates the magnetic field within the closed coil.Magnetic lines can be envisioned as a sequence of circular patterns aligned with the axis of the current.Ultimately, the ferromagnetic plunger is drawn towards the coil owing to the presence of the magnetic field.This valve incorporates components that can be easily substituted at a low cost. It can be adaptable to various operations or machinery, and it offers a traditional design that consumes minimal power and exhibits rapid response times [9].

Fig. 6. Pneumatic Solenoid Valve

2.2.3. FRL Units

Within this system, it is essential to uphold the appropriate pressure and ensure that the pneumatic air remains unobstructed. Additionally, adequate lubrication is vital for optimal pneumatic performance. In this context, an FRL unit is employed in this system, as shown in Figure 7, and it proves to be beneficial as it encompasses a filter, regulator, and lubricator components. The functions of the FRL unit are outlined below:

2.2.3.1. Filter: The filter employs cellulose felt and reusable, surface-type elements to remove impurities from the air before it enters pneumatic components such as actuators and valves. The filter elements cover a size range of 5 to 50 micrometres. Filters are employed to prevent theentrance of solid impurities into the system and to capture submicron particles that could potentially cause problems in the components of the system.

2.2.3.2. Regulator: To maintain a steady pressure within the pneumatic system, regulators are employed in this setup. Air is introduced into the regulator through its inlet, and the pressure can be adjusted by manipulating the knob. In case the pressure downstream surpasses the threshold value, it will be vented into the atmosphere using a knob. Conversely, if it attains the predetermined pressure level, it will stabilize in an equilibrium state.

2.2.3.3. Lubricator: A lubricator ensures effective lubrication for the internal moving parts of pneumatic components.This lubricator ensures the precise introduction of every oil drop into the airflow as observable through its distinct flow.The oil mist is composed of both coarse and fine particles.

Fig. 7. FRL Unit

2.2.4.Pneumatic Hoses

A hose, as shown in Figure 8, is a flexible, tubular structure designed for the purpose of facilitating the movement of fluids from one place to another. Hoses are sometimes referred to as pipes (the word "pipe" often denotes a rigid tube) or more broadly, as tubing. This distinction arises because pipes are typically rigid, while hoses tend to be more flexible. They are manufactured using materials like PVC, polyethylene, nylon, natural rubber, or synthetic compounds. The shape of a hose typically leans toward cylindrical due to its fusion of functionality and design. Factors contributing to this shape include length, weight, size, chemical compatibility, and pressure rating.

Fig. 8. Pneumatic Hose

2.3. Electrical Components

2.3.1. AT mega 8- Microcontroller

In this system, an AT mega 8 microcontroller is used, which is illustrated in Figure 9. ATmega8 is an 8-bit microcontroller utilizing the Advanced Virtual (AVR) RISC architecture and characterized by its low power CMOS configuration. The microcontroller includes the Harvard architecture that works rapidly with the RISC. It achieves both high speed and minimal power consumption by executing the program in a single clock cycle, operating at a rate of 1 million instructions per second per megahertz (MIPS/MHz). The features of this microcontroller include different features compared with others, like sleep modes, an inbuilt ADC (Analog to digital converter), an internal oscillator, and serial data communication. It performs the instructions in a single execution cycle. The device is constructed by utilizing Atmel's advanced nonvolatile memory technology with high storage capacity. The Flash Program memory can be modified within the system via an SPI serial interface, a conventional non-volatile memory programmer, or an onchip boot program that operates on the AVR core. The boot program has the capability to employ different interfaces for transferring the application program into the application flash memory. The software located in the Boot Flash Section will persist in operation during the update of the Application Flash Section, ensuring genuine read-while-write functionality. Through the integration of an 8-bit RISC CPU with in system selfprogrammable flash within a single chip, the Atmel ATmega8 microcontroller offers an efficient solution for numerous embedded control applications. This solution is characterized by its high flexibility and cost effectiveness [10].

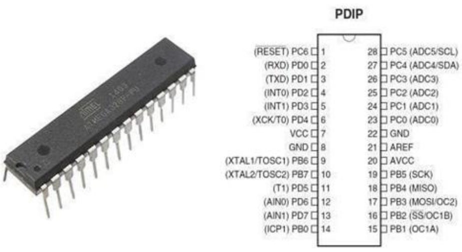

Fig. 9. AT mega 8 microcontroller

2.3.2. Relay

A relay is employed in this system, as shown in Figure 10. A relay is an electrically operated device that functions as a switch. It consists of a coil and one or more sets of contacts. Relays are commonly used to control high-power circuits using low-power control signals. Relays play a crucial role by allowing control signals to switch high-power loads without the need for direct electrical connections. When an electric charge passes through the relay's coil, it generates a magnetic field, which attracts a lever and toggles the switch contacts. This process is managed by one or more circuits receiving a low-power signal. The relay is characterized by numerical combinations that indicate the activation or deactivation of coil currents for both normally opened and normally closed positions. As a result, relays offer two switch positions, known as double-throw (changeover) switches. When the current is interrupted by the relay coil, the armature reverts to its original position of rest. A rapid surge in voltage resulting from the sudden interruption of the current supply can result in the destruction of responsive electronic components that are responsible for the circuit's operation. When the coil is designed to be powered by alternating current (AC), a certain method is employed to divide the flux into two elements that are out of phase. These elements combine, resulting in an increased minimum attraction on the armature during each cycle of the AC. Typically, this process is achieved by incorporating a small copper "shading ring" wrapped around a segment of the core enclosing the lagging, out-of-phase component [11].Relays are used to protect the electrical system and minimize the damage to the equipment connected to the system due to over-currents or voltages. The relay is used for the purpose of protecting the equipment connected to it.

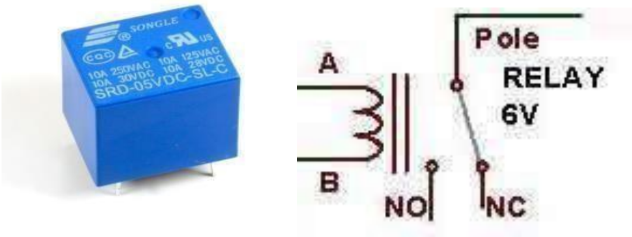

Fig. 10. Relay

2.3.3. Pressure Sensor

A pressure sensor is a device designed to measure the force exerted on a surface due to the applied pressure of a gas or liquid, as shown in Figure 11. It is used to convert the mechanical force causedby the pressure into an electrical signal that can be interpreted, displayed, or recorded by various devices. They play a crucial role in monitoring tire pressure in vehicles. Pressure sensors are integral components of emergency air filling systems in vehicles, particularly in situations that require rapid and precise tire pressure adjustments. This system relies on pressure sensors strategically placed within each tire to continually monitor pressure levels. When a significant pressure drop is detected, these sensors communicate with the vehicle's control unit, triggering alerts on the dashboard to notify the driver of the issue. Subsequently, the control unit employs the pressure data to initiate the emergency air filling mechanism. This mechanism, often integrated with an air compressor, inflates the affected tire to the appropriate pressure level, thereby enhancing vehicle safety, performance, and handling. The pressure sensor module, specifically the MPX

2202A, is designed to accurately measure pressures up to 200 KPa. This corresponds to a pressure range of 0 to 29 psi. The module offers a full-scale output of 40 mV with a sensitivity of 0.2 mV per KPa. It operates within a supply voltage range of 10 to 16 V DC. Despite its compact size, this mini module is capable of delivering precise pressure measurements, making it suitable for various applications that require reliable pressure sensing. With applications ranging from aerospace to consumer electronics, pressure sensors continue to advance, becoming more compact and integrated to meet modern technological demands.

Fig. 11. Pressure Sensor

3. Design Calculation and Specifications

Maximum power = 2.61 Kw at 5000 rpm
Maximum torque =5.0 at 3750 rpm
Power derived from Gear 1 is given by,
Power, $P=\frac{2\pi NT}{60}$
$P=\frac{2\pi(3750)(5)}{60}$ ⟶ (1)
Therefore, Power(P)= 1.965kW
The crankshaft produces a output power of 1.965 kW. Transmission Ratio is given by,
$I=\frac{D_1}{D_2}=\frac{N_2}{N_1}=\frac{Z_1}{Z_2}$
Where ,
D_n= Diameter of the gears
Z_n= No of teeth in gears
N_n= Speed of the gears.
Here, D_1=70 mm
D_2=70 mm
Therefore, Transmission Ratio, I =1.
Power obtained by Gear 2=1.965kW
Power transmitted from gear 2 to gear 3 is calculated as follows:
D_3=160 mm
Transmission Ratio is given by, $I=\frac{D_3}{D_2}=\frac{160}{70}=2.2857$ ⟶ (2)
We know that, $I=\frac{N_2}{N_3}$
$2.2857=\frac{3750}{N3}$
N_3=1640.635rpm Therefore,
Power obtained by the compressor $(P)=\frac{2\pi(1640.635)(5)}{60}$ ⟶ (3)

Power, P=0.859034kW.

4. Mechanical and Electrical arrangements

It refers to how various parts and elements are positioned and interconnected within a system. In a mechanical arrangement, components such as gears, compressors, and bearings are positioned to enable proper functionality and movement.

The electrical arrangements of components are shown in Figure 12. The electrical arrangement involves the positioning of a microcontroller, relay, pressure sensor, and other electrical elements to facilitate the flow of electricity and ensure the system's electrical operations.

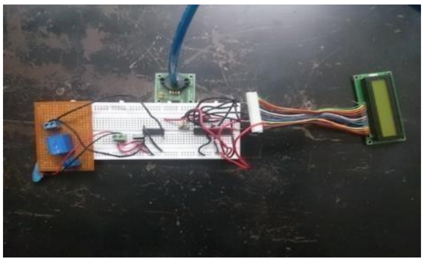

Fig. 12. Electrical arrangement

5. Result and Discussion

At any instance, the air pressure inside the tyre tube decreases.This prompts the driver to exit the vehicle and rectify the situation by adjusting the tube using a knob located at the opening of the tyre tube, which is integrated into the pressure sensor module [12]. The resultant pressure from the tyre tube produces an alternative output voltage, which in turn facilitates the cylinder's extension and retraction processes. The microcontroller receives input from the alternative output voltage, examines the input signal, and then generates an output signal based on the programmed instructions within the controller. Usually, a solenoid valve directs the airflow from one terminal of the double-acting cylinder to the other terminal. Once the controller sends its input signal to the solenoid valve, the valve shifts its position, thereby causing the pneumatic supply to switch and flow towards the cylinder's opposite end. Notably, the cylinder's retraction or extension is determined by the tyre pressure. The gears remain interconnected throughout the extraction process. Even as the cylinder is in motion, the gears remain engaged, ensuring the synchronization of various components. This level of coordination is a key factor in the seamless operation of the system. The vehicle can be initiated while in neutral, and the gear connected to the crankshaft triggers the rotation of two additional gears. Subsequently, the compressed air from the compressor is then directed into the second tube and becomes infused with air. Thus, this safety system provides an effective and immediate solution at the time of tyre punctures. This system enables the vehicle to cover further distances even after experiencing a tyre puncture by effectively maintaining the appropriate tyre pressure. Significantly, it empowers the driver to safely navigate their vehicle to a mechanic workshop, and further maintenance of the tyre can be carried out. The aim of a tyre pressure monitoring system, integrated with in-vehicle technology, is to assist drivers in upholding the appropriate tyrepressure for their vehicles. This, in turn, mitigates the potential for accidents caused by tyre-related issues [13]. Maintaining the proper tyre pressure prolongs the lifespan of the tyre and decreases fuel expenses [14]. By preventing sudden tyre deflation and maintaining optimal pressure levels, it minimizes the risks associated with accidents caused by loss of control. The emergency air filling system is not merely a technological marvel but a practical solution to a common and persistent issue.It ensures the inconvenience and hazards of tyre punctures are significantly reduced.This system not only contributes to the vehicle's safety and efficiency but also showcases the integration of technology for a smoother driving experience.

Fig. 13. Final setup

6. Conclusion

The development and implementation of an emergency air filling system in vehicles represent a significant advancement in automotive safety and efficiency. This innovative system, relying on a compressor to deliver the necessary air, highlights the importance of accurate design and precise calculations for optimal efficiency. The core objective of this system is to promptly and effectively address the tire punctures, which is accomplished with precision and reliability. This represents an innovative system designed for inflating the tire tube when it experiences a puncture. By integrating this technology into vehicles, this system not only enhances safety but also mitigates the stress and inconvenience often associated with tire emergencies, particularly in remote or challenging terrain areas. This comprehensive solution contributes not only to individual vehicle safety and performance but also to broader societal goals. Reduced instances of underinflated tires can lead to fewer accidents and a decrease in greenhouse gas emissions, promoting environmental sustainability. Moreover, the convenience offered by this technology enhances the overall driving experience for consumers. In conclusion, the emergency air filling system in vehicles is a promising innovation that has the potential to revolutionize automotive safety and efficiency. As this technology continues to evolve and become more accessible, we can look forward to safer roads, reduced environmental impact, and enhanced driving experiences for all.

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