

Evolution of tire inflation systems: from manual pumps to semi-automated or automated technologies

Kunal Dewangan^{1*}, Nutan Diwan¹, Kalyani Bohare¹ and Divyaneer Ratrey¹

¹Department of Mechanical Engineering, New Government College Raipur, Chhattisgarh, India.

ABSTRACT Manually inflating tires is history now; this is a careful scrutiny that unravels the revolution in tire inflation technology and examines its transition from simple systems to sophisticated computer-based systems aimed at improving safety, fuel consumption, and tire lifespan. Maintaining the correct level of tire pressure is critical towards minimizing rolling resistance, facilitating easy handling, and avoiding accidents. This research presents a detailed analysis of the evolution of tire inflation systems, ranging from centralized inflation to rotary joint mechanisms and sensor-based monitoring systems. It further examines some selected research articles on wind-driven and air pumping filling systems, listing their benefits, shortcomings, and future applications in contemporary vehicles. This paper delves into the history of development of tire inflation systems from manual pumps to semi-automated and fully automated technologies. The research brings into perspective the effects of contemporary tire inflation systems on the safety of vehicles, fuel efficiency, and the lifespan of tires. The main aim of this research is to evaluate technological progress in tire inflation and determine the challenges that come with their mass uptake. The study suggests that automatic tire inflation systems would be capable of significantly enhancing vehicle performance and efficiency but are being prevented from mass consumption by challenges such as being expensive, complicated to integrate, and requiring maintenance. Upcoming developments are predicted to centre on durability enhancement, cost minimization, and real-time monitoring integration to increase efficiency and feasibility

Keywords: *Automated Technology; Fuel Efficiency; Real time tire pressure monitoring; Rotary joint; Tire inflation system; Vehicle Performance; Vehicle safety*

1. INTRODUCTION

Early tire inflation was performed using a hand pump, a very manual, laborious, and time-consuming way to inflate tires. In recent years, technology met the challenge, and a more efficient alternative found its way into our bags, portable all-in-one tire inflator now comes to deal with those ill-inflated tires. Reportedly, as many as 34% of cars in India are running

* Corresponding author: nutandiwan1802@gmail.com

on under-inflated tires whereas 44% were found to have over-inflated tires, a fact that, unfortunately, is far too common when it comes to improper tire pressure, as derived from a survey by Tire Review Magazine. Underinflated tires not only raise the risk of accidents but also degrade ride quality and fuel economy. Proper tire pressure is critical to improving vehicle handling and safety. The increasing popularity of in-car tire inflators indicates a reaction to the problems presented by underinflated tires. This review will analyse tire inflation systems, presenting the strengths and weaknesses of these devices and opportunities for innovation in rival inflation technologies.

1.1 Novelty of the Study

Although previous studies have concentrated on the fundamental working of tire inflation systems, the present study is a complete overview of their development, innovation in technology, and challenges involved. The research ensures that there is minimal knowledge gap in understanding the implementation of automated tire inflation systems and their implications in real-world applications.

2. REVIEW

[1] Singh et al. (2007) researched an automatic tire inflation system to ensure optimal tire pressure, which improves vehicle safety, fuel economy, and tire life. The system employs a rotary joint mechanism to control pressure, solving problems resulting from underinflated tires, including higher fuel consumption and tire wear. The main components are a battery-driven compressor, an air pass rotary joint, and a nozzle in the wheel rim for high airflow.

The main components constituting the system are:

- Rotary Union: Supports air transfer but allows rotation movement.
- Compressor: Provides compressed air and is powered by the electric system of the vehicle.
- Wheel Hub and Nozzle Assembly: Enables proper delivery of air in the tire.

The study focuses on a number of advantages of the system:

- Extended Tire Life: Properly maintained pressure prevents excessive tire wear.
 - Improved Fuel Efficiency: Proper inflation reduces rolling resistance.
 - Enhanced Safety: Lowers risk of tire blowout and accidents.
 - Maintenance Cost Savings: Reduces repair and replacement rate of tires, along with the costs involved.
 - Environmental Benefits: Lower fuel usage translates into fewer emissions.
- Nevertheless, the report does acknowledge certain limitations as well:
- Maintenance Problems: Rotary joints and seals require constant maintenance.
 - Retrofit Costs: Retrofitting is expensive for existing vehicles.
 - Integration Challenges: Integration with newer vehicle electronic architectures is an area requiring more work.

The study points out that automatic tire inflation systems are aligned with current smart automotive technology. Future research should focus on enhancing durability, reducing cost, and incorporating real-time monitoring. The systems can be implemented for passenger vehicles, commercial vehicles, and off-road vehicles.

As a whole, they enormously enhance the efficiency, safety, and sustainability of vehicles. Regardless of the challenges currently faced, further research and advancements in technology will improve the reliability and affordability of such systems, further boosting their contribution to the automobile industry.

[2] Mushiri et al. (2016) suggest a self-inflating tyre system driven by a wind turbine-compressor system, minimizing maintenance requirements and fuel dependency. It critically analyses its purpose, research methodology, findings, and implications for automotive maintenance, in particular, tyre pressure management. Inflation irregularities cause fuel inefficiency, tyre deterioration, and safety hazards. The computerized system reduces human intervention and maximizes performance, which differentiates it from conventional tyre inflation.

The approach method used to carry out the research is robust. The researcher integrates:

- Computer-aided design (CAD) for designing and modelling the system.
- Java/Android programming for implementing sensor technology for autonomous pressure monitoring and control.
- Wind-driven turbine mechanism, which converts the kinetic energy of air drag into mechanical energy for a small compressor that inflates the tyres whenever needed.
- Mathematical modelling for computation of air-drag force, wind energy conversion efficiency, and power output of the system.

The research presents elaborate calculations in Favor of the system's viability and presents strong proof of its applicability in real-time.

The paper presents a number of key conclusions:

- Power output of the wind turbine is sufficient (50.2W) to drive the compressor at a vehicle speed of 25 km/h.
- The system is environmentally friendly, powered fully by renewable wind energy with no emissions.
- The automated feature of the system ensures tyres to be at the best pressure level, thereby saving fuel and improving tyre life.

The research depends on simulation and theoretical models rather than experimental measurement, indicating necessity for experimental measurement in real applications to determine effectiveness of the system under different drive conditions.

The pioneering wind turbine-driven tire inflation system improves car technology by doing away with the need for physical checks and being independent of outside energy supplies. It saves fuel and increases tire longevity, which could bring substantial long-term cost savings for car owners.

But the study has some limitations:

- It is largely hypothetical, and a working model and field trials would be needed to prove it.
- The turbine requires a minimum vehicle velocity, which can be a restriction to its applicability in urban driving.
- Mounting the turbine-compressor unit on the wheel is cause for concern about additional weight and real estate.

There should be further research that develops and tests a physical model in actual driving conditions, looks at other sources of power at low speeds, and optimizes design to avoid interfering with the vehicle's performance.

This paper suggests an automated tire inflation system based on wind power, having a strong theoretical basis with the benefits of fuel economy and the environment. But practical verification by prototype testing is essential for the development of further automated tire inflation systems and eco-friendly automotive technology.

[3] Rathi (2017) propose a major improvement in car safety and performance with an automated tire pressure management system. This study emphasizes the adverse effects of incorrect tire pressure, including excessive wear, lower fuel efficiency, and safety hazards.

The system comes with a centralized compressor that inflates all four tires to optimum pressure automatically, tracked by a pressure sensor with real-time information displayed on

an LCD. With the use of rotary valves and an Arduino-based control system, the system inflates automatically without the intervention of drivers.

This new system improves vehicle stability, handling, and braking while lowering fuel consumption and prolonging tire life, resulting in cost savings. The authors specify the components of the system for easy comprehension, mentioning that its applications are not limited to passenger vehicles but can extend to military, public transit, and industrial applications.

The additional components, such as the compressor and sensors, add complexity to the vehicle, weight wise, which may offset fuel efficiency gains. The system necessitates a permanently operating compressor, adding to energy consumption and upkeep. The absence of experimental data in the paper raises questions about the credibility of the system, and while it addresses independent operation, it ignores integration issues with existing vehicle systems.

This system represents a major step forward for tire pressure control, with potential benefits in terms of safety, efficiency, and convenience for users. Yet, real-world trials and cost-benefit studies would be necessary to determine its suitability for mass use. Future developments should focus on weight reduction, energy efficiency, and compatibility with intelligent vehicle technology.

[4] Kumar Purwar (2017) study delves into the "Automatic Tire Inflation System" (ATIS), which keeps tires in optimal pressure in cars to enhance fuel efficiency, safety, and tire life. The research traces the history of ATIS to military vehicles such as the American DUKW trucks of 1942 and points to information from AAA and NACFE on the adverse effects of underinflated tires. The ATIS works on a compressor that fills tires when pressure is low.

Major parts are:

- Rotary Joint: Permits air flow while avoiding hose tangling.
- Compressor: Sustains tire pressure with pressurized air.
- Air Delivery System: Regulates air supply through hoses and check valves.
- Pressure Gauge and Sensors: Regulate pressure and avoid overinflation.

The system provides advantages such as less tire wear, more efficient fuel use, less driver input, increased safety, and extended tire life, leading to improved vehicle performance and lower environmental footprint. It also suffers from the downside of requiring periodic maintenance of parts and possibly high installation fees.

The article highlights the significance of Automatic Tire Inflation System (ATIS) in contemporary cars towards enhancing safety, efficiency, and longevity. Though presently available for heavy-duty and military applications only, ATIS has tremendous prospects for passenger cars by keeping tire pressure at optimum levels and cutting down energy losses.

The article is informative and well-structured, outlining ATIS's working principles. It would be improved by empirical evidence, comparison with conventional tire pressure monitoring systems, and cost-benefit analysis.

In conclusion, the paper offers a detailed overview of ATIS and its applicability in modern cars, with its pros and cons. Further studies can be conducted on cost-effective maintenance and wider use in commercial vehicles and passenger cars, making the study a resourceful document for automotive technology professionals.

[5] Rajkumar (2017) study presents an automated tire inflation system that dynamically adjusts optimal tire pressure. Under-inflated tires can adversely affect vehicle performance, fuel economy, and safety, but most drivers do not know their tire pressure. This system solves these problems by automatically maintaining tires inflated without driver intervention.

The system features a central compressor that delivers air to all four tires through rotary joints, pressure sensors, and an electronic control circuit. The rotary joints are located in a way that enables air transfer without hose tangling. Pressure sensors check tire pressure, engaging the compressor when it falls below 20 PSI, filling the tires up to a maximum of 30

PSI. The process of inflation ends once this capacity is attained and air cannot move back into the compressor due to a non-return valve.

The system offers various advantages, such as better fuel economy, lower tire wear, and increased vehicle safety. Proper tire pressure reduces rolling resistance, resulting in better fuel economy and a smaller environmental footprint. It also increases tire life and lowers maintenance requirements while enhancing handling, stability, and braking performance for safer driving.

Nonetheless, experimental verification and field test outcomes are not included in the design, which means its performance under different conditions cannot be confirmed. Additional studies are required to determine the practicability of implementing the system in current vehicles, such as costs of installation and maintenance, and the long-term viability of major components such as rotary joints and pressure sensors.

While the article emphasizes the significance of tire pressure and suggests a pragmatic solution, further studies on actual performance and cost estimation are essential to assess the system's commercial viability and long-term performance.

[6] Abbi & Ramakrishnaiah (2021) research presents a novel tyre pressure monitoring system (TPMS) that improves vehicle safety through ongoing tyre pressure, temperature, and wheel alignment analysis. In contrast to conventional TPMS, which merely notifies drivers whenever tyre pressure drops below a predetermined level, this system presents real-time critical tyre data, minimizing the risk of accidents.

The device comprises a pressure sensor (MPX10DP), temperature sensor, accelerometer, Arduino microcontroller, and 433MHz RF transmitter. The pressure sensor detects tyre air pressure and wirelessly sends data to an LCD screen. It also informs the driver in case of pressure falling below 25 PSI for prompt action. Amplitude shift keying (ASK) modulation facilitates low-cost and effective transmission of data.

The study highlights the advantages of real-time monitoring, outpacing the constraints of the conventional systems. Experimental results provide stable and reliable measurements, thus promising to be an alternative option for vehicle maintenance and driver safety.

The article also recommends enhancements, including the monitoring of all four tyres at once using distinct sensor identifiers and employing a PIC microcontroller for power and size efficiency. Other features like data logging, predictive analysis, and IoT support for remote monitoring could also extend the functionality of the system.

Overall, the present study has offered a low-cost and good-designed solution for tyre pressure monitoring.

[7] The paper "Design and Fabrication of a Prototype Car Tyre Inflator" by Lazarus et al. (2020) reviews a light, portable tyre inflator driven by a 12V car battery and able to inflate tyres within 200 kPa within 3 to 5 minutes. The equipment solves the urgency required in emergencies where conventional vulcanization facilities are not available.

The authors critique prior innovations such as automatic inflation apparatus and high-performance inflators with their shortcoming in inflation duration and dependence on power. The authors promote the use of a portable, standalone inflator in order to meet these shortcomings.

The research methodology comprises material choice, design factors, and efficiency and pressure calculations. The inflator has a single-cylinder compressor, gear drive, and 12V DC motor, mounted on a rugged mild steel frame. The design relies on thermodynamic principles, supplemented by applicable equations.

In the process of manufacturing, parts were machined, welded, and assembled. Testing entailed inflating 10 tyres, with a volumetric efficiency of 85%, verifying the effectiveness of the device in supplying pressurized air within the required time.

The findings demonstrate that the inflator performs satisfactorily to achieve the set pressure and time of inflation. The discussion provides insight into design parameters'

influences on performance. The authors advance suggestions such as air delivery automatization and improving cylinder numbers in order to promote efficiency. Contrast with current commercial tyre inflators would further exhibit the advantages of the prototype.

The paper ends with a confirmation of the device's functionality and usability, suggesting future improvements like automation and scalability for enhanced user experience. Although the viability of the prototype is proven, additional field testing under diverse conditions is necessary for a comprehensive reliability evaluation.

Strengths:

- Thorough theoretical analysis and calculations.
- Properly documented fabrication and test procedures.
- Practical application to emergency situations.

Limitations:

- No comparison with current commercial products.
- No market viability discussion or cost analysis.
- Overheating upon prolonged usage is not well discussed.

Overall, this study gives useful information about a portable car tyre inflator, showing its feasibility and assisting automotive maintenance technology. In the future, efficiency should be optimized, testing conditions be widened, and commercial viability be assessed.

[8] The research "Automatic Tire Inflation System" by Ghag (2022) presents a new approach to keeping the tire pressure of cars at the optimum level, highlighting its significance in terms of fuel efficiency, tire life, and safety. The research is aimed at developing an automated system for tire pressure monitoring and adjustment continuously.

Ghag points out that most cars use under-inflated tires, which cause more fuel to be used and pose safety threats. The system consists of a pressure meter, electric sensors, a rotary joint, and a compressor of air that turns on to fill tires when it senses low pressure.

The key component is the rotary joint, enabling air transfer from a fixed source to the turning wheel, with dynamic seals and ball bearings for effectiveness. The system also uses an Arduino Nano, a 433MHz transmitter, and a battery-powered sensor for live tire pressure information. The innovation is set to improve vehicle handling, safety, fuel efficiency, and tire life.

The research addresses a key automotive maintenance challenge, promoting better fuel economy and road safety through modern technology integration, including microcontrollers and radio frequency communication for tire pressure management.

The manuscript focuses on theoretical design and CAD modelling but lacks empirical testing to validate the system's performance. While it discusses the system's advantages, it does not address cost implications or the feasibility of large-scale implementation across different vehicle types. Moreover, a lack of comparison with current tire inflation systems makes it difficult to determine the innovative nature and efficiency of the presented solution. Discussion on the wear resistance and serviceability of the rotary joint and pneumatic seals should be increased.

The "Automatic Tire Inflation System" provides a novel solution to tire pressure control based on automated sensors and a rotary joint system for improving vehicle efficiency and safety. Yet, more research has to be conducted to examine the prototype under practical conditions, assess its cost implications, and compare it with current technologies. This paper adds to automotive engineering and paves the way for future developments in intelligent tire technology.

[9] Agasthee Jain et al. (2022) research emphasizes the need for proper tire pressure in cars and reports results of a study on Centralized Tyre Inflation Systems (CTIS) based on ANSYS simulations. The study emphasizes the role of tire pressure on vehicle stability, performance, fuel efficiency, and safety and counters the prevalent problem of underinflated tires by means of automation and real-time monitoring.

The research delves into CTIS's working principles, which enable dynamic tire pressure to be adjusted according to speed, load, and road surface, citing its extensive application in military and forestry vehicles for increased mobility and reduced costs. The system consists of parts such as compressors, air tanks, pressure gauges, and electronic controls.

The approach is to look at current tire inflation methods, choose materials, and design with CAD, and then simulate ANSYS to analyse performance. Test field work on cement tankers under different conditions is to compare fuel efficiency improvement.

Field tests revealed very little fuel reduction from Central Tire Inflation Systems (CTIS), with Truck 2 cutting fuel use by 1.22% and Truck 1 adding 0.84%, for an overall improvement of only 0.19%. While CTIS helps tire life and road safety, its impact on fuel economy is uncertain.

The strengths of the study involve good literature review, good methodology, and a practical aspect. It is weakened, though, by its small sample size, ambiguous fuel efficiency findings, absence of cost analysis, and inadequate description of ANSYS simulations.

The study highlights the contribution of CTIS in ensuring tire pressure and safety, yet fuel efficiency advantages remain inconclusive, requiring additional study with more diverse samples and conditions. Advanced data analytics and machine learning need to be incorporated into future research to enhance tire pressure prediction and inclusive cost-benefit analyses. Though the article gives insights worth consideration, more empirical data and costing are necessary to support its conclusions.

[10] Negemiya et al.'s (2024) article presents a new solution to the problem of inappropriate tyre inflation in cars, pointing out its relevance to performance, fuel economy, and safety. Inspired by the widespread issue of under-inflated tyres that result in wasted fuel and higher accident rates, the research sets forth an automatic tyre pressure inflation system. This system keeps monitoring and regulating tyre pressure with elements such as a pressure switch, solenoid valve, AC motor, and DC compressor. If tyre pressure varies from the specified level, the pressure switch triggers the solenoid valve to inflate the tyre up to the desired pressure, reducing human intervention and improving safety. The study outlines the components and operations of the system, with a prototype to show its applicability. The system ultimately promises improved fuel economy, tyre wear reduction, reduced maintenance costs, and improved road safety.

The main limitation is the high implementation cost. Future studies need to investigate more cost-effective options, including the integration of this technology with what is already available for vehicle tracking. Maintenance will be needed for items like the pressure switch and compressor, but the research doesn't provide any information on their lifespan. Though there is a prototype described, the research does not discuss functionality in various vehicles, and there could be customization available that would increase its utility. Comparative examination against existing tyre pressure monitoring technologies would have underscored the advantages of this technology. This paper introduces a novel automatic tyre pressure inflation system with the potential to enhance road safety, vehicle performance, and fuel efficiency. While its viability is confirmed, more studies are necessary to resolve cost-effectiveness, maintainability, and wider vehicle applicability. The results provide significant contributions to automotive engineering and intelligent vehicle systems [11,12].

In general, the study provides a solid platform for industrial usage and further investigation, possibly allowing integration with digital tyre pressure sensors and IoT-based vehicle management systems.

3. Comparative Analysis

Table:01 (Comparative Analysis)

Study	System Type	Inflation Mechanism	Control Mechanism	Energy Source	Key Benefits
Singh et al. (2007)[1]	Tire Inflation System	Rotary joint and nozzle	Pressure monitoring	Vehicle battery	Fuel efficiency, tire wear decrease, safety enhancement
Mushiri et al. (2016)[2]	Automatic Inflation System for Small Vehicles	Wind-driven turbine-compressor	Java/Android monitoring	Independent power source	Environment friendly, self-sustaining
Rathi (2017)[3]	Central Air Inflation System	Rotary valves and centralized compressor	LCD display alerts	Vehicle power supply	Fuel efficiency, wear reduction, safety improvement
Kumar Purwar (2017) [4]	Automatic Tire Inflation	Compressor and rotary joint	Pressure gauge monitoring	Vehicle battery	Fuel efficiency, improved handling, accident prevention
Rajkumar (2017)[5]	Automatic Tire Inflation System	Compressor and rotary joint	Pressure sensors	Vehicle battery	Gas mileage improvement , tire wear reduction
Abbi & Ramakrishnaiah (2021)[6]	Tire Pressure Monitoring System (TPMS)	Electronic pressure sensors	Microcontroller-based alert system	Vehicle battery	Real-time monitoring, improved safety
Lazarus et al. (2020)[7]	Prototype Car Tire Inflator	Reciprocating compressor	Manual activation	Car battery	Portable, efficient inflation
Ghag (2022) [8]	Automatic Tire Inflation System	Compressor and rotary bearing	Automated pressure regulation	Vehicle battery	Fuel savings, tire longevity, handling improvement
Agasthee Jain et al. (2022)[9]	Centralized Tire Inflation System	Air compressor	ANSYS-based simulation	Pneumatic system	Adaptability to varying road conditions
Negemiya et al. (2024)[10]	Automatic Tire Pressure Inflation	Compressor and rotary joint	Electronic TPMS integration	Vehicle battery	Compliance with safety regulations, improved performance

3.1 Inflation Mechanisms

Recent literature strongly supports the use of a compressor to supply air through a rotary joint or valve system, with a constant air supply during travel. Interestingly, the study by Mushiri et al. presents a wind-powered turbine-compressor, offering a green alternative to conventional techniques.

3.2 Control Mechanisms

Control systems vary from mere pressure gauges and sensors to highly complex ones involving microcontrollers and Java/Android-based monitoring solutions. More advanced studies, including Jain et al. (2022), utilize ANSYS-based simulation for improving inflation performance.

3.3 Energy Sources

Whereas the majority of systems use the vehicle's battery for energy, Mushiri et al.'s work indicates an independent power source via a wind turbine, which is a more energy-efficient source compared to traditional battery-powered systems.

3.4 Key Benefits

All systems are designed to improve vehicle efficiency, improve tire life, and improve safety. Tire Pressure Monitoring Systems (TPMS) provide real-time monitoring, allowing for proactive maintenance. Centralized tire inflation systems also dynamically vary inflation levels as a function of load and road conditions, improving adaptability.

4. Evolution of Tire Inflation Systems

Manual Inflation: The first tire inflation used manual pumps, which were a laborious and constant requirement.

Semi-Automated Systems: With the rise of technology, pressure monitoring devices came into use that helped in keeping tires at proper pressure.

Fully Automated Systems: Current cars have computerized tire inflation systems that can automatically adjust pressure according to road conditions and load.

5. Impact of Automated Tire Inflation Systems

Enhanced Safety: Proper tire pressure minimizes blowout risk and improves vehicle stability.

Fuel Economy: Inflated tires minimize rolling resistance, decreasing fuel usage.

Tire Longevity: Avoidance of underinflation and overinflation helps to avoid tire wear.

6. Barriers to Adoption

Initial Expenses: Installation and use of automated technology are costly.

Integration Complexity: Implementing automated technology in older cars is technically challenging.

Maintenance Requirements: Advanced systems require regular upkeep, increasing operational costs.

7. Conclusion

The innovation in tire inflation technology has greatly enhanced the efficiency, safety, and environmental sustainability of vehicles. The present review showcases several innovations, including automatic inflation systems, centralized systems, and sensor-based pressure monitoring. Though such advancements have many advantages, like enhanced fuel economy and less tire deterioration, they have certain challenges also, such as durability-related issues, integration complexity, and up-front costs. Overcoming these challenges using better materials, extensive road testing, and economical fixes will be important to more widespread acceptance, especially in the passenger car market. As intelligent vehicle technologies continue to advance, integrating intelligent tire inflation systems with Internet of Things (IoT) and artificial intelligence (AI) diagnostics will go further in increasing vehicle performance and safety, maybe making these systems standard features for the future of automotive engineering. Key Findings are:

- The automation of tire inflation increases safety, improves fuel efficiency, and prolongs the life of tires.
- High costs and integration challenges hinder the widespread adoption of this technology.
- Future initiatives should emphasize cost-effectiveness and ease of implementation.

REFERENCES

1. I. Singh, B. P. Singh, H. S. Sahu, R. Chauhan, Implementation of tyre inflation system for automotive vehicles. *Int. J. Innov. Res. Sci. Eng. Technol.* 5 (2016). <https://doi.org/10.15680/IJRSET.2016.0504014>
2. T. Mushiri, A. T. Muzhanje, C. Mbohwa, Design of an automatic tyre pressure inflation system for small vehicles (2016)
3. K. Rathi, Automatic central air inflation system. *IOSR J. Mech. Civ. Eng.* 17, 01–03 (2017). <https://doi.org/10.9790/1684-17010060103>
4. S. K. Purwar, Automatic tire inflation system. *Int. Res. J. Eng. Technol. (IRJET)* (2017)
5. M. Rajkumar, Automatic tyre inflation system (2017)
6. A. Abbi, T. Ramakrishnaiah, Tyre pressure monitoring system. *IOP Conf. Ser.: Mater. Sci. Eng.* 1042, 012024 (2021). <https://doi.org/10.1088/1757-899x/1042/1/012024>
7. T. L. Lazarus, P. C. Okolie, E. S. Abonyi, Design and fabrication of a prototype car tyre inflator (2020)
8. P. Gupta, S. Kumar, Liquid crystal polymers: Thermo-optical-mechanical coupling and actuations, in *2024 1st Int. Conf. Sustainability and Technological Advancements in Engineering Domain (SUSTAINED) (IEEE, 2024)*, pp. 831–835
9. P. Ghag, Automatic tire inflation system. *Int. Res. J. Eng. Technol. (IRJET)* (2022)
10. R. A. Jain, J. Murugesan, K. Naveen, Study and analysis of centralized tyre inflation system using ANSYS 7 (2022)
11. H. S. Ruhela, S. Bhardwaj, T. Agrawal, P. Gupta, Explicit dynamics analysis of shin pads using finite element analysis, in *Int. Conf. Industrial Problems on Machines and Mechanism (Springer, Singapore, 2022)*, pp. 683–690
12. P. Rout, A. K. Jha, P. Gupta, B. Singh, S. Choudhury, Failure analysis of composite plate under ballistic impact. *Mater. Today Proc.* 74, 1008–1011 (2023). <https://doi.org/10.1016/j.matpr.2022.11.385>