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AUTOMATIC GEAR OIL FILLING MACHINE FOR AUTOMOTIVE ENGINES: A REVIEW OF RECENT ADVANCES AND FUTURE PROSPECTS

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Abstract
Automatic gear oil filling technology has evolved significantly in recent years, aiming to automate and optimize the precise filling of engine oil into the automotive engines. Different techniques exist to monitor, control and automate gear oil-filling machines for automotive engines, and some are also in their developmental stage. This review provides an overview of the current state of automatic gear oil filling technologies, including their types, benefits, and challenges. The study also highlights recent advancements and future directions in this field. The review began with the history of the gear oil filling technologies for automotive engines and how they evolved to their current form. The study combines both qualitative and quantitative research methods, leveraging a combination of research papers, articles, reports, patents, and technological developments related to gear oil filling technologies.

Introduction

Automatic gear oil filling machines for automotive engines are specialized systems designed to handle the precise and efficient filling of gear oil into engine compartments or containers used in automotive manufacturing and maintenance. These machines are vital in automotive assembly lines where speed, accuracy, and reliability are critical. Automatic gear oil filling machines for automotive engines are essential for the efficient and precise dispensing of gear oil during manufacturing or maintenance. Several research articles and industry insights discussed and presented various types of automatic gear oil-filling machines for automotive engines. These studies explore diverse approaches, from using advanced controllers to modeling physical processes, offering both theoretical insights and practical solutions for automatic oil-filling systems in the automotive context. For instance, Shekar et al. [1] presented an Automatic Filling Unit by using Programmable Logic Controller (PLC). This system integrates the precision of the PLC technology with the efficiency of the automated filling processes.

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It focuses on designing a reliable and precise filling unit controlled entirely by a PLC, ensuring consistent and accurate filling operations. The PLC serves as the brain of the system, orchestrating the various components such as sensors, motors, and valves to achieve seamless filling processes. The implementation of this system not only enhances the productivity of industrial units but also reduces human intervention, minimizing errors and ensuring a higher level of safety. Josh et al. [2] introduced a bottle-filling machine using Programmable Logic Controller (PLC) based controller in the automation industry. The main a bottle filling machine aim of the paper is to design and fabricate a small and a simple filling system using PLC. The belt conveyor is used for moving the bottle. The position of the bottle is detected by the infrared sensor so that the pump can function at the right time. When the bottle is under the tank, the pump is started and the bottle is filled with water. All the components perform well. This filling machine is cost-effective and can be used in small-scale bottle-filling systems such as coffee shops, juice shops and other beverage industries. Abubakar et al. [3] discussed the design and development of an automated liquid-filling system using a robotic arm conveyor. The system is designed for small-scale industries and uses an Arduino Mega 2560 microcontroller to control the robotic arm and other components. This section describes the components used in the system, including the robotic arm, Arduino controller, infrared proximity sensor, relay, and pump. It also explains the methodology used to develop the system and the results obtained during testing. Similarly, Rao et al [4] explored the optimization of an automatic gear oil-filling machine using artificial intelligence, providing insights into the application of AI in improving the efficiency and accuracy of gear oil-filling machines. Powerrig Machinery [5] examined the role of automated oil-filling machines, focusing on features like volumetric control, overflow prevention, and integration into production lines to enhance efficiency. An analysis of an oil-filling system for assembly lines showcased the integration of modified control systems to reduce operator waiting times. Using advanced pneumatic and mechanical designs, these systems achieved better workload distribution and zero waiting time, significantly enhancing productivity. Kumar et al. [6] also presented the design and implementation of an automatic gear oil-filling machine using Programable Logic Controller (PLC) and sensors to improve the efficiency, accuracy, and safety of the gear oil-filling process. The article found that the designed and implemented automatic gear oil-filling machine using PLC and sensors is a reliable, efficient, and cost-effective solution for the manufacturing industry. Patel et al [7] introduced the design and implementation of an automatic gear oil-filling machine for automotive engines using Programable Logic Controller (PLC) and sensors to improve efficiency, accuracy, and product quality. An automatic gear oil-filling machine integrated with a vision inspection system to improve efficiency, accuracy, and product quality was developed by Chen et al. [8]. The article concludes that the developed automatic gear oil-filling machine with a vision inspection system is a reliable, efficient, and cost-effective solution for the manufacturing industry. Lee et al. [9] also proposed an automatic gear oil-filling machine with an integrated quality control system to improve efficiency, accuracy, and product quality. Kumar et al. [10] analyzed the design and development of an automatic gear oil-filling machine for automotive engines to improve efficiency, accuracy, and product quality. The article concludes that the designed and developed automatic gear oil filling machine is a reliable, efficient, and cost-effective solution for the automotive industry. Singh et al. [11] developed an automatic gear oil filling machine integrated with a robotic arm to improve the efficiency, accuracy, and flexibility in filling gear oil for automotive engines. A comprehensive review of the design and analysis of an automatic oil-filling pump, focusing on hydraulic systems used in industrial applications, was also done by Chodavadiva et al. [12]. The study discussed the challenges of manual oil filling and proposed an automated solution to improve the efficiency and accuracy. Akintunde et al. [13] presented a study on the development of a pneumatic multi-purpose gear oil refilled. The device provides equipment that helps in the efficient refilling of gear oil in automotive engines. Abdollah et al. [14] also proposed a semi-automatic machine designed to replace the gearbox oil in automotive engines,

highlighting the benefits of automation in maintenance processes. A systematic approach to design and develop an automatic gear oil-filling machine to improve efficiency, reduce labor costs, and enhance safety in the manufacturing process by Kumar et al. [15]. Mahajun et al. [16] presented a review on the development of an automatic filling machine controlled by a Cypress microcontroller. While the focus is on resin filling for capacitor insulation, the methodologies discussed can be applied to automatic oil filling systems in automotive applications. Chen et al. [17] comprehensively discussed the design and performance of an automatic gear oil-filling machine integrated with a vision inspection system to improve the efficiency, accuracy, and product quality of automotive engines. Kulkarni et al. [18] designed and fabricated an oil measuring and dispensing machine used in small industries and automobile workshops. This study discusses the mechanisms and design considerations relevant to the development of efficient oil dispensing systems. Patil et al. [19] also developed an automatic edible oil filling machine. Although this study focuses on edible oil, the automation principles and mechanisms are relevant to automotive oil filling systems. Ardi and Defi [20] proposed a modification to the control system using PLCs to improve the loading and unloading processes. The study found that the modification of the control system using PLCs improved the loading and unloading processes in the oil-filling machine, resulting in increased efficiency, productivity, and safety. Zhang et al [21] focused on the oil-filling process of wet clutches in automatic transmissions, providing insights into modeling and control strategies that can be applied to the design of automatic oil-filling machines. Singh et al. [22] also examined the development of an automatic gear oil-filling machine integrated with a robotic arm to improve efficiency, accuracy, and flexibility. Kim et al. [23] studied the development of an automatic gear oil-filling machine integrated with an automated capping and labeling system to improve efficiency, accuracy, and product quality. Sheth et al. [24] designed an automatic fuel-filling system using a mechatronics approach, aiming to improve the efficiency, accuracy, and safety of fuel-filling applications. The article found that the designed automatic fuel-filling system using a mechatronics approach is a reliable, efficient, and safe solution for fuel-filling applications. Sarode et al. [25] also presented the development of a PLC-based automated oil-filling system for engine hydro-mounts. This automated system consists of a PLC, sensors, actuators, and a human-machine interface (HMI). The PLC controls the filling process, monitors the oil level, and detects any errors. The study found that the PLC-based automated oil-filling system is a reliable and efficient solution for engine hydro-mounts. The system can be easily integrated into existing manufacturing processes, and its modular design allows for easy maintenance and upgrades. Lee et al [26] developed an automatic gear oil-filling machine with an integrated filling and capping system that can be used as a reliable, efficient, and cost-effective solution for the manufacturing industry. Ciminieri et al. [27] also developed an integrated clutch filling phase control for gearshifts on wet clutch transmissions, focusing on heavy-duty vehicle applications. This study provides insights into the control strategies that can be applied to the oil-filling processes in automatic transmissions. This review presents a detailed review of automatic gear oil-filling machines for automotive engines, which includes an in-depth analysis of the systems, state-of-the-art technologies, design considerations, challenges, innovations, and advancements in the field.

2.0 Method

The methodology used in conducting this review on automatic gear oil-filling machines for automotive engines involves a multi-faceted approach to assess the technology's effectiveness, usability, safety, and environmental impact. The review started with the history of the automatic gear oil filling technologies and how they developed into their current form. The study combines both qualitative and quantitative research methods, using a combination of research papers, articles, reports, patents, and technological developments related to automatic gear oil-filling technologies.

2.1 Literature Survey

Automatic gear oil-filling machines are integral to modern automotive manufacturing and maintenance. These machines ensure the precise, efficient, and consistent filling of gear oil in vehicles. From the first manual methods of filling gear oil into the automotive engines using hand-operated pumps, funnels, or ladles to the integration of sophisticated automated systems. These early machines were simple, mechanical devices that relied on gravity-fed systems to fill the gearboxes with oil. They were often cumbersome, prone to errors, and required frequent maintenance. The concept of a mechanized gear oil-filling machine emerged in the 1950s. The first automatic gear oil-filling machines were developed in the 1950s and 1960s, primarily for use in high-volume production environments. This literature review provides an overview of the current state of automatic gear oil-filling machines, including their types, benefits, and challenges.

2.1.1 Early Automotive Assembly (1900s–1930s)

In the early 20th century, the gear oil was filled manually during automotive assembly. This process relied on hand-operated pumps, funnels, or ladles. It was labor-intensive, prone to spillage and inconsistent in terms of oil volume and quality control.

Challenges:

- Inconsistent oil quantities led to performance and maintenance issues. Slow production
- Rates limited automotive output during the rapid expansion of the industry [28].

2.1.2. The Emergence of Mechanized Filling (1940s–1950s)

The wartime pushes for efficiency influenced the advancements in mechanized assembly lines, including rudimentary fluid transfer systems. Early mechanized gear oil filling systems appeared in high-volume automotive factories. Basic pneumatic pumps were introduced, reducing manual labor. These systems improved the speed but still required significant human oversight [29].

2.1.3. Automation and Precision (1960s–1970s)

As automation became widespread, industries adopted gear oil-filling systems with semi-automated capabilities. Machines with metering devices and basic control systems ensured that accurate volumes of oil were delivered. Introduction of volumetric and gravimetric filling technologies for greater precision. Conveyor systems integrated with filling machines enabled higher throughput

2.1.4. Advancements in Automation (1970s-1980s)

The 1970s and 1980s saw significant advancements in automation technology, including the introduction of Programmable Logic Controllers (PLCs) and computer numerical control (CNC) systems. Automatic gear oil-filling machines began to incorporate these technologies, allowing for greater precision, accuracy, and efficiency. Machines from this era were still relatively simple, but they marked a significant improvement over their predecessors [30].

2.1.5. Modernization and Robotics (1990s-2000s)

The 1990s and 2000s saw the widespread adoption of robotics and computer-aided design (CAD) software in the development of automatic gear oil-filling machines. Machines from this era were highly advanced, featuring precision-crafted components, advanced sensors, and sophisticated control systems. They were capable of filling gearboxes with high accuracy and speed and were widely adopted in the automotive industry [31].

2.1.6. Industry 4.0 and Beyond (2010s-present)

The 2010s saw the emergence of Industry 4.0, a trend that emphasizes the use of advanced technologies, such as artificial intelligence (AI), the Internet of Things (IoT), and big data analytics. Modern automatic gear oil-filling machines incorporate these technologies to achieve even greater levels of precision, accuracy, and efficiency. They are also designed to be highly flexible and adaptable, allowing them to be easily integrated into various production environments [32].

2.2 Types of oil-filling machines

Various types of engine oil filling machines cater to different production needs, with considerations for factors like the "engine oil filling machine price" and the level of automation. These include [33]:

- Manual Engine Oil Filling Machines

Suitable for smaller-scale operations, manual machines involve operator control, offering a cost-effective option.

- Semi-Automatic Engine Oil Filling Machines

Combining automation with some manual aspects, these machines strike a balance, often at a moderate engine oil filling machine price.

- Automatic Engine Oil Filling Machines

Fully automated models streamline the filling process, ensuring precision and efficiency although they may have a higher initial engine oil filling machine price.

- Net weight of engine oil filling machines

These precision machines, often automated, use weight-based measurements and may be priced higher due to their advanced features.

- Volumetric Engine Oil Filling Machines

Measuring volume accurately, volumetric machines offer versatility, with pricing influenced by the level of automation.

- Rotary Engine Oil Filling Machines

Designed for continuous high-speed operations, rotary filling machines may have a higher "engine oil filling machine price."

- Piston Engine Oil Filling Machines

Piston-driven machines offer precise filling, and their pricing may vary based on the automation features.

- Gravity Engine Oil Filling Machines

Gravity filling machines, suitable for low-viscosity oils, may present a cost-effective option.

- Positive Displacement Engine Oil Filling Machines

Using displacement mechanisms, these machines offer accuracy, with pricing influenced by automation and technology.

- Overflow Engine Oil Filling Machines

Overflow filling machines ensure consistent fill levels, and their pricing may be influenced by automation and production capacity.

When selecting an engine oil filling machine, businesses must consider their production requirements, precision needs, and budget constraints, including the engine oil filling machine price. The choice between manual, semi-automatic, and automatic options depend on the balance between the initial investment and the long-term efficiency gains in the production process [34].

2.3 Recent Innovative Designs on Gear Oil Filling Machines

Recent research and development efforts have introduced several innovative designs aimed at enhancing the efficiency, precision, and versatility of gear oil filling machines for automotive engines. Notable advancements include the following:

- Pneumatic Multi-Purpose Gear Oil Refiller

Researchers have developed a pneumatic device designed to assist technicians, students, and vehicle owners in easily filling transmissions and differentials with oil. This equipment simplifies the refilling process, reducing manual effort and minimizing spillage [35].

- Flex-Fill Packaging Innovation

Valvoline has introduced the FlexFill bag, a patented packaging solution that facilitates the easier changing of synthetic gear oil. This flexible and less wasteful design caters to automotive do-it-yourself enthusiasts, enhancing user convenience and reducing environmental impact [36].

- Multi-Purpose Mechanical Pump for Refilling and Recovering

This study focused on developing a manual mechanical pump capable of both refilling and recovering gear oil and other automotive fluids. This device operates without electricity and utilizes a vacuum pump mechanism to transfer liquids efficiently. It is particularly beneficial in settings where electrical power may be unavailable or where cost-effective solutions are needed [37].

- Automated Design of Gerotor Oil Pumps

Advancements have been made in the automated design of geroton oil pumps, which are integral to the oil hydraulics in automotive engines. These developments focus on optimizing the pump efficiency and reliability, contributing to the improved performance of oil-filling systems [38].

- Electric and Variable Displacement Oil Pumps

The automotive industry has seen the introduction of electric and variable displacement oil pumps. These innovations offer improved efficiency by adjusting the oil flow based on the engine requirements, leading to better fuel economy and reduced emissions [39].

2.4 State-of-the-Art Automatic Gear Oil Filling Machines for Automotive Engines

Modern automatic gear oil-filling machines are cutting-edge systems designed to meet the demands of precision, speed, and efficiency in the automotive industry. These machines leverage advanced technologies to ensure accurate and reliable filling processes. Figure 1 depicts a typical modern automatic gear oil-filling machine. State-of-the-art automatic gear oil-filling machines typically incorporate the following features:

- High-Accuracy Dispensing: Advanced dispensing systems ensure precise control over the amount of oil filled, minimizing waste and ensuring the correct lubrication levels.
- Automatic Oil Identification: Machines can identify the type of oil required for each gearbox, eliminating errors and ensuring that the correct lubricant is used.
- Real-Time Monitoring: Advanced sensors and monitoring systems enable real-time tracking of the filling process, detecting any anomalies or issues.
- Integrated Quality Control: Machines can perform quality control checks, such as verifying the oil level, checking for leaks, and detecting any contaminants.
- Flexibility and Adaptability: Modern machines can accommodate various gearbox types, sizes, and configurations, making them versatile and adaptable to different production lines.
- Industry 4.0 Compatibility: Many machines are designed with Industry 4.0 principles in mind, enabling seamless integration with other smart manufacturing systems and technologies.
- User-Friendly Interface: Intuitive interfaces and controls enable operators to easily navigate and manage the machine's functions [40].

Figure 1: A typical state-of-the-art gear oil-filling machine

2.5 Technologies Used

State-of-the-art automatic gear oil-filling machines often employ cutting-edge technologies, including the following:

i. Robotics and Automation: Robotic arms and automated systems enable precise and efficient filling processes.
ii. Artificial Intelligence (AI) and Machine Learning (ML): AI and ML algorithms can optimize filling processes, predict maintenance needs, and detect potential issues.
iii. Internet of Things (IoT): IoT connectivity enables real-time monitoring, remote control, and data analytics.
iv. Computer Vision: Computer vision systems can inspect the filling process, detect anomalies, and verify the correct oil level [41-42].

2.6 Benefits

The adoption of state-of-the-art automatic gear oil-filling machines can bring numerous benefits to automotive manufacturers and maintenance facilities, including the following:

- Increased Efficiency: Automated filling processes reduce labor costs, increase productivity, and minimize downtime.
- Improved Accuracy: Precise control over oil filling ensures the correct lubrication levels, reducing the risk of gearbox damage or failure.
- Enhanced Quality Control: Integrated quality control checks ensure that the gearboxes are filled correctly, reducing the risk of defects or warranty claims.
- Reduced Waste: Accurate dispensing systems minimize oil waste, reducing the environmental impact and costs.
- Improved Safety: Automated machines reduce the risk of operator injury or exposure to hazardous materials [43-45].

2.7 Future Developments

The future of automatic gear oil-filling machines is expected to be shaped by emerging technologies such as

- Increased Adoption of Industry 4.0 Principles: Machines will become even more integrated with other smart manufacturing systems, enabling seamless communication and optimization.
- Advancements in AI and ML: Machines will become more intelligent, enabling predictive maintenance, real-time optimization, and improved quality control.
- Development of New Materials and Technologies: New materials and technologies, such as nanotechnology and advanced sensors, will enable further improvements in machine performance, efficiency, and accuracy [46-49].

2.8 Challenges in the Gear Oil Filling

Some challenges in designing efficient and effective automatic gear oil-filling machines are discussed in this section.

i. Viscosity of the Gear Oil: High viscosity requires specialized pumps and nozzles. It also requires maintaining the oil at the optimal temperature to reduce resistance.
ii. Consistency and Accuracy: Preventing underfilling or overfilling due to fluctuating flow rates.
iii. Leakage and Contamination: Designing effective seals and ensuring that the filling lines are free from contaminants.
iv. Compatibility with Automotive Standards: Machines must adhere to automotive quality assurance standards (e.g., ISO/TS 16949).

v. Handling High Viscosity: Requires robust pumps and wide-bore nozzles to maintain the flow rates.

vi. Environmental Variability: Performance can vary with temperature changes affecting the oil viscosity.
vii. Precise Volume Control: Essential to prevent damage to automotive engines due to incorrect oil levels.
viii. Multi-Specification Compliance: Ability to handle different types of gear oil for diverse automotive models.
ix. Environmental and Safety Considerations: Anti-drip mechanisms and precise controls reduce oil waste.
x. Compliance: Machines must meet environmental regulations (e.g., for hazardous waste disposal).
xi. Safety Features: Emergency shut-off systems and enclosures to protect operators from moving parts must be incorporated [50-51].

3 Conclusion

The history of automatic gear oil filling technologies reflects a continuous evolution driven by the desire to meet the demands of precision, speed, and efficiency in the automotive industry. These machines leverage advanced technologies to ensure accurate and reliable filling processes. From early manual gear oil-filling machines to sophisticated, automated systems that use IoT connectivity, advanced sensors and robots, gear oil-filling technology has come a long way. The recent innovative designs reflect a concerted effort to improve the functionality, efficiency, and user-friendliness of gear oil-filling machines in the automotive sector. By incorporating advanced technologies and user-centric features, these developments meet the evolving demands of modern automotive maintenance and manufacturing. Finally, robots and smart technologies promise to further revolutionize the automatic filling of gear oil technology in the future.

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