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System design and mechatronics of an air supply station for air-powered scooters☆

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ABSTRACT

This study developed an air supply station for air-powered scooters. The station comprised mechanical and electrical systems. The key components of the mechanical system were a high-power air compressor, low-pressure cylinder, pneumatic boosting cylinder, high-pressure accumulator, and target tank. The electrical system comprised pressure sensors, air flow sensors, and control circuits, which were equipped adequately for the air charge. An air-powered scooter was used to evaluate the design specifications and charging performance of the station, and the scooter was tested on a chassis dynamometer to assess performance during a modified standard driving cycle. The experimental results confirmed that the air supply station can produce high-pressure air for air-powered vehicles. The station design can guide the development of similar technology by companies in the transportation and green energy industries. Future research will conduct a theoretical analysis by modeling and simulating the performance of the air station and air scooter.

1. Introduction

1.1. Motivation

The rise of green energy and environmental protection laws worldwide has prompted the use of several types of zero-emission energy, such as solar, hydrogen, wind, and electrical energy, on various platforms. Because energy used in transportation influences the environment substantially, automobile manufacturers worldwide have increasingly focused on developing vehicles powered by green energy. In particular, electric vehicles (EVs), hybrid electric vehicles (HEVs), and plug-in HEVs have been equipped with different configurations or combinations of lithium batteries, fuel cells, supercapacitors, air motors, and electric motors. For meeting zero-emission requirements in the future (particularly municipal requirements), electrical, hydrogen, and air power are the three major options. In consideration of the cost and maturity of air power, the technology appears to have promising potential for application in green vehicles. Therefore, the efficient supply of air to vehicles is crucial for commercialization. This paper presents the design of an air supply station with two operation modes. The function of the station was verified using a modified air-powered scooter.

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1.2. Literature survey

Electrical energy charging systems as well as many fast-charging batteries and battery swapping technologies have been developed in past decades to promote the production and use of EVs [1, 2]. The development of air-powered vehicles has occurred relatively recently; thus, a few studies have investigated air supply systems. However, research on air-powered vehicles, engines, and motors has become increasingly crucial. For air-powered systems, various methods for producing high-pressure air were have been compared [3]; for example, high-pressure air was supplied to the vane-type air motor of a hybrid pneumatic/electric motor [4]. In addition, an adaptive backstepping sliding mode control was used to control a highly nonlinear vane-type air motor [5]. Similarly, a fuzzy model reference adaptive control (MRAC) controller was designed for vane-type air motor systems [6]. A lumped-parameter system based on control volume and isentropic nozzles was used to simulate an air motor to investigate the detailed parameters of the vane-type air motor of air-powered vehicles [7]. In another study, an air-powered light-duty motorcycle was developed, and its performance was evaluated, with particular attention paid to its cruising mileage and speed [8]. Furthermore, a vehicle with a conventional engine was converted to an energy-saving hybrid vehicle by using a pneumatic power system to recapture wasted energy from the exhaust pipe [9]. Another study reported that the air supply for air-powered vehicles can be in one of two forms: compressed gas or cryogenic liquid [3]. Engines related to these two forms have been investigated.

The air piston engine has become widely used because of its higher efficiency compared with that of other air motors. In [10], a low-cost hybrid drivetrain with a pneumatic system consisting of an air tank and compressor–expander was developed and showed 26% efficiency for a round trip. In [11], a new air engine for a motorbike was also presented. A mathematical model was constructed for specification evaluation. Next, a prototype engine was constructed and compared with a simulated engine. The performance efficiency was approximately 70–95%. In [12], a high-efficiency pneumatic motor system was developed. The energy in compressed air/pressurized hydraulic oil was converted to mechanical energy by using a hydraulic motor. This experiment confirmed that theoretical evaluation is possible. Moreover, in [13], a four-stroke gasoline engine was converted to a two-stroke air engine, and the performance and cost were compared. Finally, in [14], a mathematical model was formulated for an air engine, and the calculation results were compared with experimental results. Thus, the relationships among dimensionless parameters (rotational speed, exhaust pressure, inertia) were studied.

The aforementioned literature indicates the growing focus on air power for transportation vehicles. Thus, the aim of this study was to develop an air supply station for air-powered vehicles. The remainder of this paper is organized as follows. Section 2 describes the system design and mechatronics of the proposed air supply station. The system configuration is introduced first, an air-powered scooter is then established and tested, and finally the system specifications are presented. Section 3 describes the development of the air supply station. Section 4 details the experimental results of the air-charging station to demonstrate the feasibility of the design. Finally, Section 5 summarizes the contributions of this research.

2. System design and mechatronics

2.1. System configuration

The system configuration of the proposed air supply station is illustrated in Fig 1. An air compressor delivers compressed air to a low-pressure cylinder for storage. At the output of the cylinder, a 110 ACV solenoid valve (SV) directs the compressed air into a pneumatic boosting cylinder according to the pressure received from the air accumulator tank that is downstream from the pneumatic boosting cylinder. The pneumatic boosting cylinder increases the output pressure to a value 10 times that of the input pressure. Once the pressure in the accumulator tank decreases because of the air flow to the vehicle's air tanks, the pressure transmitter delivers a signal to the SV to input more air into the accumulator tank. The high-pressure air then flows to multiple high-pressure tanks controlled by their own SVs and switches. The four check valves shown in Fig. 1 are used to prevent air backflow. The normal charge mode requires the user to take the empty air bottle to a supply station; once the bottle connector is engaged, air is fed to the air compressor to be compressed, and the bottle is filled with high-pressure air. In the tank exchange mode, the user directly replaces the empty bottle with an already filled bottle.

Fig. 2 illustrates the hardware arrangement of the key components. AC 220-V electric power is used for the air compressor (1) to pump the compressed air into the low-pressure cylinder (2). The stored air is then controlled by a SV (3) and delivered to the pneumatic boosting cylinder (4) to further increase the air pressure. The air travels through a check valve that prevents backflow (5) and into the high-pressure accumulator (6), which stores high-pressure air. The flow meter (7) downstream from the accumulator tank controls the flow rates of air entering the flow distribution devices (8), where the air flow for the user's air tank (9) is controlled by a set of SVs. Several pressure transmitters measure the pressures of the bottles and the high-pressure accumulator for control issues.

2.2. Air-powered scooter test

To determine the system specification of the air supply station, a dynamometer test of an air-powered scooter was implemented. A 130-kg electric scooter was modified into an air-powered scooter according to the procedure used in a previous study (Fig. 3). Because the modified scooter is rear drive, the same as the original electric scooter was, a 1-kW four-blade