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CONCEPTION OF VEHICLE OF INDIVIDUAL PERSONAL TRANSPORT WITH HYBRID PNEUMATIC PROPULSION

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Abstract

This paper describes the conception of an individual personal transport vehicle. The conception of the vehicle is based on a mechanical structure of a bike and on a pneumatic engine as equipment of power support. The research was done as an analysis of existing vehicles with main or supporting gas power systems. In the research the expectations of users, technical resources as well as known constructions were taken into account. At the beginning, the technical properties of known methods and modern vehicles available for individual personal transport of people were reviewed. Next, some vehicles which can meet economic, ecologic and environmental criteria were identified. Finally, the authors proposed usage of extremely small and light-weight vehicles. It appears that the smallest, lightest and most economic construction of vehicles should be modeled on the bike. For power convenience on uphill roads compressed air as a supporting power factor was proposed. It also implied the possibility to use supporting power system as main power engine. However, the economic storage and management of compressed gas required optimization system of gas usage. This optimization depends on pulse wide modulation of air valve flow and possibility of air compression. Air compression is possible by driving downhill or on fixed vehicle by human muscle power. Those circumstances warrant to name such power system a hybrid pneumatic propulsion.

Keywords: *individual personal transport, ecologic vehicles, air powered vehicles, pneumatic vehicles, hybrid pneumatic and human power propulsion*

1. Introduction

The prospect of dwindling fossil fuel resources and environmental considerations make people interested in topics related to transportation issues. One particular aspect of transport is the issue of individual personal transport. From the observations it is known that several types of different transport vehicles designed for four, five or more people usually transport one person only. Very often their main motivation is only to change location without transport of goods. In the current technical conditions individual usage of transport vehicles by one person only to change location is a costly venture from economic point of view, is wasteful from energetic point of view and can be interpreted as harmful to the natural environment. Usually the public transport is pointed as an alternative to individual use of transport vehicles designed for many persons. However, it is commonly known that for various reasons many people are not in favour of public transport. Situation like that provokes the following questions: Why do same people avoid public transport? Is their choice motivated by prestige or convenience? Is it the question of time constraints or logistics? Are health reasons at play? Why are many people willing to incur additional costs, although it is technically possible to avoid them? Although finding a fully convincing explanation of human behavior is probably impossible, we can certainly consider whether there are alternatives to individual personal transport by conventional cars. It is to this issue that further considerations are devoted. They are narrowed to land transport and mainly relate to short-distance movement.

Commonly known logistic analysis of the personal land transport shows dependences between choices of transport vehicles and expected travel time. It means that we can observe some statistical trend that statistically understood member of the public society tends to devote daily between half an hour to a maximum of two hours of travelling. It is emphasizes that the travel time is the most important factor. In the expected travel time different people by different types of transport vehicles can travel different distances. It indicates dependences between expected travel time, type of vehicles, distances and logistic organization of human society. We can expect that if the logistic organization of human society allows people to satisfy all their needs within a smaller area, it will decrease the needs to overcome long distances. Consequently, if needs to overcome long distances have been decreased, it will naturally affect the choice of type of vehicles. In this way, selection of slower type of vehicles intended for local traffic organization instead of vehicles of long distances becomes a rational choice. Therefore it can be concluded that the use of different types of vehicles is inspired not only through individual preferences of people but mainly by structural organizational solutions of public transport and foundations of the logistic organization of human society. In this way, the different logistic organizational structures of human society and different social trends result in the use of different types of vehicles. In the case of individual personal transport usually first the type of a vehicle is chosen. After that a decision is made whether the journey can be taken individually, whether the journey can be taken by a small group, or whether there are any reasons to alter the initial selection of the vehicle. Usually it is iterative process. Finally, rational compromise between intentions and possibilities is conscious.

Increasing public transport offers do not always correspond to the expectations of potential passengers. From psychology we know that every man or woman instinctively seeks to optimize the level of stimuli. If it is true than in large population centers, many people will seek to individualism. In sparsely populated areas a greater tendency to take collective projects can be seen. Accordingly, we can predict that the strengthening of public transport in sparsely populated areas will be better accepted by the local community, than in areas of higher density of human population. So we can formulate a thesis that in large urban areas a greater interest in individual personal transport vehicle should be expected than in rural areas. However, the technical and organizational issues of individual personal transport or public transport in large density of population centers will be of greater importance. In the instinctive tendency to choose any kind of public transport or individual personal transport the following factors are also taken into account: the time we need to transport (on average one hour per day), the distances covered (associated with a maximum speed of chosen type of vehicle), compensation of individuality and prestige due to the subcultures of the high or low human population, health issues, transportation costs, and the local road system.

Environmental aspects are very important in the large urban areas and in large density of human population centers. For this reason so-called eco-friendly vehicles with very low energy consumption and low emissions are searched. Past experience indicates that vehicles meeting these expectations should be light and small [1]. In that point of view, ideally they are vehicles for a single person. In this case the weight of the vehicle can be minimized and anticipated transport capacity will be fully used. This will avoid the empty runs. In fulfillment of these criteria it is important that expected cost of the vehicle should be as low as possible.

These elements have caused the pursuit to identify constructions of vehicles that can provide individual personal transport in large urban areas. If the vehicle is created, there is nothing to prevent the use of it as well in the area of low density of human population. However, the primary motivation in investigating the problem was the possibility to provide local, ecologic, healthy and cheep individual personal transport vehicle.

2. The use of natural human capabilities of energy making

Movement is good for health. For the reasons health it is recommended for everybody to move in certain optimal time range, intensity and geometric dimension. It is believed that too little and too much physical activity is harmful to human health. Observations about the negative health consequences of sportsmen and sportswomen should not undermine the general principle that movement is healthy (not harmful) for the human body. Based on the foregoing it can be concluded that an optimum range of physical activity of human body should be done in work or in spare time. Any cultural limitations in this area bring more losses than profits. For that reason the development of different devices designed to make life easier should be limited to avoid degeneration of the health and physical abilities of mankind. Under these circumstances the expectations concerning the use of natural human ability to power vehicles of individual personal transport seems to be justified.

Physical work has accompanied mankind in its long history. People's ability to perform physical work was most visible in slavery. A lot of useful work is done today as well through the usage of human physical force. Focusing on energetic aspects it might be asked: How much work should we expect of a single human worker? Many answers to many similar questions were examined in the early years of the twentieth century. The conclusion can be summarized in the form of power density factor which equals 0.5 W/kg. For comparison, a typical electric motor has a power density factor of about 100 W/kg. This value is difficult to increase in commonly used electric motors. Typical internal combustion engines usually have power density factors of about 200 W/kg. Power density factors of the best Stirling engines are reaching 300 W/kg. The highest known today power density factors of internal combustion engines achieve 400 W/kg. From the theoretical point of view, the power density factors should be calculated accordingly to unit of volume. But usually the power density factors are calculated accordingly to unit of mass. That is very useful for practical purposes because measurement of weigh is easier than measurement of volume. However, in reference to the human body, it is significant that the fat tissue is lighter than muscle tissue. The previously given value of power density ratio of the human body was specified for averaged time of work estimated to six hours a day. It has been concluded after much research that working six hours a day is safe for human health because the risk of exhaustion is low in long period of working activity during human live. This allows to preserve health in spite of long-term operation. Probably for similar reasons legislations of many states considered 42 hours as normal weekly working time. Intellectual work and physical work are treated as equivalent in legislation point of view because of similar oxygen consumption.

With regard to use natural movement ability of human body in different methods of individual personal transport we should pay particular attention to walking, running, skating, cycling or going by Segways. Walking is the most economical way of individual personal transport to a distance of 5 km. The average walking speed of an adult human is usually estimated as 5 km/h (1.4 m/s). Sometimes normal walking speed is estimated as 3.6 km/h (1 m/s) [3]. If we take into account the expected travel time of a person up to one hour, then we can specify optimal distance of walking as 3.6 km or 5 km for a person per day. Usually it relates to the closest neighborhood of residence. That conclusion is convergent with recommendation of health reasons of human body. It is recommended to walk the distance 5 km per day for men and 3 km per day for women. These recommendations take into account the proper stimulation of: bones, tendons, muscles, cardiovascular system, digestive system and respiratory systems of human body. Power consumption factor of a walking man is estimated circa 0.007 kW/kg [2]. Its value is smaller at slow speeds of movement and exponentially increases with the rising speed.

Any human runs when walking speed is deemed unsatisfactory. Speed of running usually depends on the distance. The maximum speed of long distance during any marathon (42.195 km) is approximated as 20 km/h (5.6 m/s). The maximum speed during middle distances (0.8 to 1.5 km) is approximated as 24 km/h (6.7 m/s). The maximum speed during sprint running (to 0.5 km) is approximated as 35 km/h (9.7 m/s). The current world record in 100 meters sprint is 36 km/h (10 m/s). Power consumption factor of the running human is small at the low speeds of movement and proportionally increases with the rising speed. At the usual speed of running its value is estimated circa 0.014 kW/kg [2]. It means than a running human body consumes twice as much energy or more as the same body during walk. But by speed over 9 km/h energy consumption during the run is smaller than the fast gait, because the run includes a short phase of flight. However, we know from experience that everybody can go further by walking than by running. For this reason, no style of running was considered as a convenient method of individual personal transport. Also there are stronger cultural prejudices towards running than towards walking. Very often any kind of running can be regarded as an exceptional event and provoke intervention of security officers. For this reason, in some countries, running is considered as a potential threat to personal safety.

Skating is sometimes considered as an alternative to walking and alternative to some kinds of vehicles convenient to individual personal transport. However, from practice we know that this mode of travelling is dangerous in urban centers. For this reason, in many crowded places skating is formally banned through legislation. For example, this applies to interior of any vehicles of public transport. Other striking example is one of the alleys of Hyde Park in London, where fine gravel was attached to the pavement to prevent skating.

Cycling is the most economical way of individual personal transport to a distance of 10 km [2]. Normal speed of a bike is about 10 km/h (2.8 m/s) but some people can reach speeds up to 50 km/h (14 m/s), and even more. It is estimated that the coefficient of energy efficiency of cycling can reach values up to 30% [2]. Power consumption factor of cycling is estimated as 0.004 kW/kg. This factor of cycling is smaller at slow speeds of movement and exponentially increases with the speed rising. It is approximately two times lower according to the value of power consumption factor of walking. Moreover, cycling consumes 47 times less renewable energy of human body in the same distance than a car that consumes seven liters of petrol per 100 km [2]. Finally we can say that cycling has the smallest energy consumption of all other methods of individual personal transport. Additionally, in cycling renewable energy of human body is used instead of fuels or energy source in other types of individual personal transport vehicles.

Segways are sometimes seen as an alternative to walking. But segways are electric vehicles and due to high cost they cannot compete with walking or cycling. Speeds of segways reach up to 20 km/h (5.6 m/s) with range up to 20 km. The movement by segways is comfortable and usually is faster than the natural walk. But segways require special service and time-consuming charging of electric accumulators. The cost of such a vehicle is about 40 times higher than the cost of an ordinary bicycle. Additional, in Polish legislation, power of installed electric motors of about 1 kW will qualify a vehicle like that to the class of mopeds, which require a driving licenses of category B or AM, which has very important consequences. Segways should only move on roadways which in Poland involves some risk.

3. Conception of bike with pneumatic propulsion

Cycling seems to be a very interesting mode of individual personal transport in densely populated urban centers. Bikes need relatively little space and are ecological because they do not produce any kind of air pollution. Probably for this reason in some of the larger cities in Poland bike rental is promoted [7]. In that enterprise a cost-competition with local public transport is very important. An example of a bike rental station is shown in Fig. 1. It seems very optimistic but, unfortunately, cycling depends on weather conditions. There is a tendency to use the bicycles in positive Celsius temperatures, during dry, windless weather, and when the planned route is approximately flat. An additional complication in Poland is the acute lack of infrastructure such as cycle lanes. Same private statistic of cyclers suggest that daily cycling during a long period of time (about 3 years) on public roads usually ends up with a crashes with car. The temperature and weather conditions are independent of human factors. On the other hand, people can largely decide on the route selection in terms of its profile, the type of surface which determines mechanical resistance of movement, and the choice of technical equipment supporting uphill move of a bike. The issue of technical support for cycling is the subject of the following discussion.

Fig. 1. An example of bike rental station in Poznan

The Polish Supreme Court in its judgment of February 4, 1994 – III KRN 254/92 assumed that the mechanical vehicle on public roads in Polish legislation is any vehicle powered by any engine [3]. It means that in Polish legislation system no bicycle is understood as a mechanical vehicle [3]. A similar point of view applies to bicycles equipped with a small auxiliary engine. But Polish legislation classified vehicles with working capacity of main or auxiliary engines. In vehicles classifying as mopeds working capacity of engine is smaller than 50 cm^3. Motorcycles and cars have bigger volume of working capacities. The same classification applies to vehicles powered with any auxiliary engine.

In Polish legislation every bike as "a non mechanical" vehicle must have possibility to be operated in a way typical of a bike [3]. But they could have any kind of auxiliary engine with power smaller than 250 W (Watts) [3]. According to [5], a bicycle is a vehicle powered by muscle of human with width up to 0.9 m. Any bicycle may be equipped with a supporting system of power. Auxiliary system of power may be actuated with a reaction of pedal pressure. But auxiliary electric motor supply voltage must be lower than 48 V and continuous power rating must be lower than 250 W. Additionally, the output of power should by progressively reduced and drops to zero at speeds above 25 km/h. Summarizing it, a vehicle can by legally regarded as a bike according to two main criteria. In the first criterion the vehicle can be powered by human muscles. In the second criterion an auxiliary electric motor has maximum power smaller than 250 W [5], but the possibility to power vehicle only by human muscles is important.

In Polish legislation system of public traffic bike is not classified as mechanical vehicle or motor vehicle [5]. To ride a bike after the age of 18 no special permission is required, ID card only is sufficient [4]. Any person leading a bike is classified as a pedestrian in Polish legislation system. Children under the age of 10 may ride a bike, without any special legal permission, only under the supervision of an adult person[6]. Any cyclist between 10 and 18 years of age ought to have a special legal permission which called "a card of cycling" (direct translation from Polish) or after 14 years of age alternatively a driving license of category AM. "A card of cycling" can be obtained only at the 4th grade of primary school. At that grade pupils are about 11 years of age. But after that period there are difficulties in obtaining such formal documents. Even greater problems obtain after completing primary school when children are 14 years old and more, but from the formal point of view they are no longer pupils. After the age 14 each person in Poland can obtain a driving license of category AM at special examining state board.

The moped in Polish legislation system is a vehicle displaying at least one of five follows properties. The first property is that a moped cannot be operated in the manner of a bicycle. The second property is that a moped has working capacity of engine smaller than 50 cm^3. As the third property moped has an electric motor with a mechanical power smaller than 4 kW. As the forth property moped has a mass below 330 kg. Finally, a moped has maximum achievable speed lower than 45 km/h [5]. Mopeds in Polish legislation system are mechanical vehicles, but they are not engine vehicles from the legislative point of view [5]. Any person driving a moped on public roads, in traffic zones or residential areas ought to have a driving license of category AM (available from the age of 14) or category B (available from the age of 18) [4]. Driving license of category A1 (available from the age of 16) permits to drive a motorcycle with working capacity of engine from 50 cm^3 to up 125 cm^3, but additional total power should be lower than 11 kW. To drive a motorcycle up to 35 kW a driving license of category A2 is required (available from the age of 18). Driving license of category A entitles to drive a motorcycle without power limits (available from the age of 24 or from the age of 20 years for those who have had a driving license of category A2 for two years) [5]. It can be concluded that the cost of a new bike, its upkeep, moving properties of bike, possibility to rent a bike and legal availability of cycling are the most convenient in comparison to other modes of individual personal transport vehicles described above. It seems that there are possibilities to introduce technical facilities for functional properties of bikes that can make them even more convenient.

Legislation texts suggest a possibility to use electric motors as auxiliary engines to power a bike. But electric motors require usage of expensive and heavy batteries, which also have limited lifetimes. Instead of that the authors propose compressed air as an alternative to auxiliary electric power systems. The text of legislation distinguishes five intervals of power [4]. The first interval of power is between 0 and 250 W. The second interval of power is between 250 W and alternatively 50 cm^3 or 4 kW. The third interval of power is from 50 cm^3 or alternatively from 4 kW to 125 cm^3 or alternatively to 11 kW. But in the third interval of power the value power density ratio should be smaller than 0.1 kW/kg. The forth interval of power is from 125 cm^3 or alternatively from 11 kW to 35 kW. But in forth interval of power the value power density ratio should be smaller than 0.2 kW/kg. Values higher than those included in the forth interval of power are included in fifth interval of power. For the authors, the most interesting are the first two intervals because the vehicles are the smallest, lightest, cheapest and easiest to obtain legal permissions. The first interval of power includes bikes. Legal circumstances suggest the possibility to equip a bike with a small auxiliary pneumatic engine of power smaller than 250 W. In this way, from the engineering point of view, a bicycle becomes a mechanical vehicle. From a legal point of view in Poland, vehicle like that is classified as a bicycle equipped with an auxiliary drive and is not classified as a mechanical vehicle. But the power of auxiliary pneumatic engine must be smaller than 250 W.

The second interval of power includes mopeds. According to power of the existing auxiliary motors of bikes described in [2] we can predict that the second interval of power may be the most convenient. In two examples described in [2] the power of auxiliary spark motors are 500 and 580 W. But the authors of that paper are interested in the application of pneumatic engines. Probably the power of such pneumatic engines should be similar. Brief energy calculation of 10% uphill road shows the necessity to use 667 W of starting (392 W) to 10 km/h (2.8 m/s) and continuous moving with that speed (275 W). But practical verification should be done. The authors consider the speed of 10 km/h as sufficient for bikes and local individual personal transport.

Known structures of vehicles that use gas pressure [1] suggest necessity of reducing the weight of other new vehicles with similar propulsion. With respect to such circumstances bicycles are the lightest vehicles convenient for individual personal transport. In vehicles with pneumatic actuators usually all the energy is derived from one special tank of pressurized gas. The essence of the presented conception is the use of one tank with two different presser mode and pulse storage of gas. Visualization of that conception is shown in Fig. 2. The gas pressure in the high pressure mode is maximal and can be up to 20 MPa [8]. The pressure of the gas in the low pressure mode may be up to 1 MPa. Low presser mode of gas is limited by the possibility of muscle compression of gas during downhill driving or muscle movement during special stationary position of vehicle. It is possible according to maximal force of leg [9], diameter of piston ∅50 mm and 5 ratio coefficient of special gear. In this mode it is possible to fill the empty tank of gas during parking or driving. In low pressure (1 MPa) mode 45 dm^3 the tank can give 250 W in 3 minutes. In high pressure (20 MPa) mode the same tank can give 250 W in one hour. The period of one hour seems be sufficient for local individual personal transport. After draining the tank, compression of air is possible and usage of low pressure mode of tank or normal cycling. Pulse storage of compressed gas in engine propulsion instead continuous supply is also very important. It is expected that this will enable significant improvements in efficiency of energy usage.

We know that generally the second interval of power is most convenient. It means that pneumatic propulsion of bike should have power circa 500 W or more. But volume and gas pressure of tanks in the lightest conception of vehicle make it impossible in one hour route. Consequently, the authors accepted limitation of power to 250 W. Such limitation is convenient from the legal point of view. Vehicles with auxiliary propulsion to 250 W are classified as bikes and adults do not need special legal permission to use of them. More other vehicles classified as bikes can move on cycle lanes, and in bad weather conditions on pavement. Limitation of power decreases maximum velocity on flat and uphill roads. When somebody expects higher velocities or longer distances they should choose a moped with spark engine and should have legal permission.

Fig. 2. Visualization of conception of bike with two presser pneumatic propulsion 1 – high-pressure tank, 2 – pneumatic connections, 3 – pneumatic engine, 4 – battery, 5 – electrical wiring, 6 – microcontroller

The analysis of the available information indicates a need to reduce the supporting propulsion to zero for the maximum speed of about 25 km/h. The text of legislations assumes a possibility of using a special control system that responds to signals, for example, the force of legs exerted on the drive pedals. Those expectations suggest a possibility of application of any kind of energy and power optimization systems. The technical implementation of those options should be Mechatronic.

4. Results

1) It is possible to build a small vehicle with pneumatic propulsion for individual personal transport in urban conditions.
2) It is desirable to use pulse wide modulation of air valve flow for optimization of energy balance of movement.
3) It is desirable to use electronic optimization of motion of bike with pneumatic propulsion.

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