

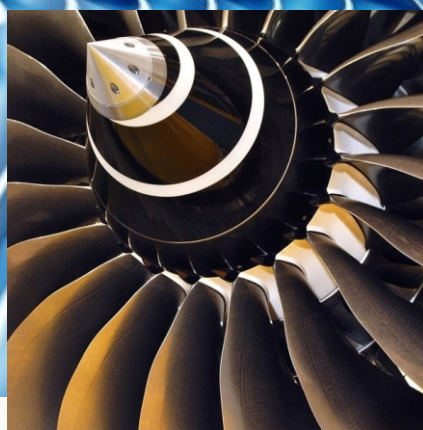
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Overview of electric vehicles on-board chargers

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Abstract: Paper deals with general overview of the electric vehicles on-board chargers, available in operation - both for new such vehicles and for those that have been obsolete, but are still moving on the roads in our country and around the world. Studies have been conducted and useful information on battery-powered electric vehicles and plug-in hybrid electric vehicles has been systematized. All this is done in connection with the ubiquitous decisive steps for large-scale and global introduction of electric vehicles, such as appropriate choice and necessity and the related topics for drastic change of the car fleet, which will cover firstly urban vehicles, the energy balances of power grids of the individual countries with a careful analysis of the expected load for normal operation, the environmental benefits, the energy efficiency and economic benefits from the use of electric vehicles and their technical improvement in the long run. In addition, under good management, the development of electric mobility can be one of the ways for achievement of employment and industrial growth.

KEYWORDS: ELECTRIC VEHICLES, LITHIUM-ION BATTERIES, BATTERY CHARGERS, CHARGING STATIONS, SUPPLY EQUIPMENT

1. Introduction

Today, the world is increasingly looking at green technology. That is why the era of electric vehicles (EVs) has come as a new field - electric mobility. Electric vehicles continue to pick up speed.

Despite the COVID-19 pandemic, sales of EVs are on the rise, with road numbers expected to reach nearly 10 million this year, according to a report by the International Energy Agency (IEA). In 2019, thanks to EVs worldwide, the consumption of nearly 0.6 million barrels of petroleum products per day was avoided [1].

If we want to stop global warming, EVs will certainly be our natural ally. Or at least this is the main view on the issue.

Nowadays electro-mobility is a booming field. Good news are rare these days, so it is good to hear that the number of vehicles with full or partial electric drives is constantly growing. This trend is just at the beginning and there is a lot of persuasion that will still have to be made to potential buyers. In addition to the range, the reliability of these vehicles is an important characteristic [2].

The EV industry is growing at an incredible pace. All major manufacturers compete on a technological level, which in turn is reflected and makes EVs more practical and meet our daily needs. Electromobility is also one of the main drivers for the development of new components and technologies. It sets new challenges for car manufacturers, OEMs and distributors are also a key factor in solving them.

How to facilitate the perception of EVs? The availability of information is essential. The basic concept of the car has not changed. But it seems that the car will change dramatically in the next ten years. Car manufacturers are increasingly focusing on electromobility. Sceptics of electromobility have raised critical questions, such as the maximum distances electric car can cover. Even the current limited mileage of some EVs of 100-150 km is still sufficient for the daily needs of most consumers. The mileage is absolutely adequate and does not create worries, especially when planning things.

It is speculative to talk about what is the most important invention for the last 200 years, but certainly the car is one of the key ones. It has made people freer and more mobile and laid the foundations of the modern world as we know it. Electric mobility is indeed here and continues to grow, but it will obviously take years before EVs become widespread enough. The market is driven by early buyers, not the mass customer.

Several factors drive the imposition of this type of car in the future. In the first place are government subsidies for the purchase of such a car in many countries, playing a major role in the choice of the customer. Another is tight EU emissions regulations, which

are forcing manufacturers to sell more EVs to meet the requirements. Third is the declining battery prices and the increased transition of EVs to convince customers that this type of car is worth it. And last but not least is the charging infrastructure, which should be convenient and relatively fast. As of June 2019, according to data from the European Commission in Norway and England, EVs charging stations are more than gasoline stations.

According to the United Nations, cities will be responsible for more than 60% of global greenhouse gas emissions by 2050, and are expected to be home to more than two-thirds of the world's population. It is therefore vital that these fast-growing urban centers take proactive measures to reduce carbon emissions, and electric mobility is a key factor in achieving this. But in order for electric mobility to be achievable in high-density cities, where time is short and space is valuable, technical solutions must be developed to meet these challenges. One of the main goals is to deploy electric vehicle mobility projects that help people commute in a sustainable fashion [3]. One of the fastest ways to accelerate the transition to an electric mobility future is to scale the electrification of fleet vehicles. Many corporates and public sector entities are now taking advantage of the low total cost of ownership. Необходими са съвместни действия на: charging station operators and service providers, car manufacturers, industry captains, national and EU policy makers, academia and corporates [4].

According to a study by the Center for Solar Energy and Hydrogen Research Baden-Württemberg (ZSW), 7.9 million electrified cars were driven worldwide in 2019 (2.3 million more than a year earlier), including passenger cars and vans, battery-powered or so-called range extender, as well as plug-in hybrid models, i.e. cars that are charged with a cable. The same study says that in 2018, there were 5.6 million electrified models worldwide. In 2019, they were 3.8 million in China and almost 1.5 million in the United States. Full hybrids and fuel cell vehicles are not included in this number. The statistics include only cars that are charged with a cable.

Electric vehicles are defined as carbon neutral, despite the carbon balance of electricity and battery production, and therefore manufacturers are increasing the share of EVs in their production range. The increase in the relative share of EVs is part of efforts to accelerate decarbonisation and is a key factor in achieving the goals of the European Green Deal and the transition to clean energy in Europe. This would help improve air quality in cities, as well as the integration of renewable energy sources into the electricity system against the backdrop of efforts to stem global warming. Climatologists announced in September 2020 that this month was the hottest in history, with unusually high temperatures recorded in Siberia, the Middle East and parts of South America. Scientists believe that high temperatures have played a major role in a number of natural disasters - from fires in California and the Arctic to floods

in Asia. For its part, Reuters announced on October 11, 2020, a call by the pope in a video address to the online conference 'Global Start Countdown - A Call for Action on Climate Change' not to invest in companies that do not protect the environment to avoid radical and catastrophic climate change.

In this regard, in recent years motor drive systems used for electric vehicles have drawn much attention and their increasing efficiency has advanced. The focus is on power conversion efficiency and loss evaluation. High efficiency, low operating costs, no emissions - there are many rational arguments in favor of the electric motor (EM). Studies of dynamic behavior and evaluation of electric power losses of induction EM drive for EV have been done in [5, 6].

Electric motor driven systems are currently responsible for 53% of global electricity consumption according to the IEA. Herein, the worldwide EV deployment will grow rapidly in the next one or two decades, and EVs supposedly become the main source of demand growth in the sustainable development scenario. Consequently, the development of more efficient EM drive systems, is one of the important technologies in the strive to reduce the global energy demand. Continuous improvement of motor efficiency of inverter-controlled EMs is a key objective and vector control of permanent magnet synchronous motors (PMSMs) is a commonly adopted technique to realize high-efficiency power conversion. Vector control technology of PMSMs to aim for ever more efficient power conversion, and ultimately contribute to finding solutions how to decrease energy consumption on a larger scale [2].

While induction EMs are more commonly found in motor-driven systems, they are often larger in size and less efficient than PMSMs solutions. While PMSMs solutions tend to have a higher initial cost, they may offer a smaller size for more compact mechanical packages and higher efficiency. Although the PMSMs offer many benefits, there is a problem of permanent magnet demagnetization when the inverter is overloaded over time. Many isolated current detection and protection components prevent the inverter from overloading and suppresses the demagnetization of PMSMs.

As a parameter, the mileage of EVs is dictated mainly by the size and capacity of the battery, the weight of the car and the performance of the EM. The actual mileage that the EV can travel on a single charge in real conditions may vary from that specified by the manufacturer. This is due to factors such as the terrain of the area through which it travels (uphill, level road or descent), the speed at which it travels, the driving style, the load in the car and the use of certain features in the car, such as air conditioning and infotainment system.

2. Technical considerations

Sales in the third quarter of 2020 in the EU are: petrol cars 47.5%, hybrids 12.4%, electric 9.9%. In the third quarter of 2020, almost every 10th car sold in the EU was electrically powered (9.9%), compared to 3.0% in the same period last year. The support measures introduced by various countries to stimulate demand for cars in the wake of the COVID-19 pandemic have put conventionally powered vehicles at a disadvantage. However, diesel and petrol cars still account for more than 75% of total EU car sales from July to September. This strong growth is mainly due to the introduction of incentives by national governments, which seek to stimulate demand in response to the pandemic, which is largely to the benefit of buyers of electric and hybrid cars. The European Commission plans to target € 100 billion for a "fair energy transition" over the next 30 years. The goal is that after 2050 the countries of the European Union will not pollute nature by burning fossil fuels. 47 measures are envisaged, including the introduction of new energy taxes, legislation on the production of batteries and clean vehicles, the installation of electric charging stations, waste treatment and more. The European Commission intends to award a € 3.2 billion mega-subsidy to seven Member States for research and innovation in the production of electric batteries. The European

Union is deeply concerned about the continent's dependence on batteries from Asia. 17 projects of European companies have been approved, and this move is part of a major push, led by Germany and France, to prepare the European Union for the mass emergence of EVs with the phasing out of petrol and diesel engines.

On the other hand, the share of electricity in the European Union produced from coal (so-called brown gold) is as follows: Poland - 81%, Czech Republic - 56%, Greece - 54%, Bulgaria - 45% and Germany - 40 %. Germany has announced that it will abandon fossil fuels by 2038 [7].

Electric vehicles also offer one of the few options for storing electricity for days and weeks. Energy storage allows for delayed and demand-oriented use, which reduces losses at production peaks and the need for other sources at electricity consumption peaks.

Noticeable advancement is the Vehicle to Grid (V2G) system wherein the battery pack in a EV could act a power source for household equipments. Some of today's EVs come with a huge battery pack upto 100 kWh making it an easy portable power house. So with the right inverter the power from these battery packs can be supplied to the grid during peak demand hours. Then these EVs can be driven to solar powered charging stations to get them charged again, building a completely green eco system.

Vehicle manufacturers are moving swiftly into EVs, and some are even trying to develop business models that integrate storage to power both cars and homes. By developing the manufacturing capability to produce storage in cars, those same companies can also offer behind-the-meter storage to customers. Community-scale EV and electric energy storage systems are a major topic in the smart city conversation since they may improve mobility while also enhancing resiliency for residents [3]. On the other hand, most of the EV owners have moved beyond just investing in charging station and now looking into intelligent charging and energy management.

Many vehicle manufacturers, such as Volkswagen, BMW and Mercedes-Benz, are already investing in their own renewable energy production facilities and will at some point start offering a closed range of products and services - both selling EVs and charging them with electricity at their objects.

What are the obstacles to the growing penetration of EVs in our daily lives, when it comes to personal light-duty vehicles? Currently, two main problems can be identified: the relatively high purchase price and the lack of sufficient charging points. At the moment, it is difficult for car manufacturers to profit from EVs, because there is one invincible factor in pricing and that is the value of batteries. According to a study by JATO Dynamics in 43 markets from the end of 2019, the average retail price of an EV is 81% higher than the average of other cars purchased by consumers [8]. The lack of charging stations makes EVs convenient for use mainly in urban conditions, i.e. their purchase is justified in order to move around the city and/or as a second car in the household. An EV is an expensive investment, but refueling is approximately twice as cheap, for example, as refueling with diesel.

By the way, according to a statement from December 30, 2019 by Christian Schulze, Marketing and Research Director of the European division of Mazda, EVs with powerful batteries are more harmful to the environment than cars with diesel engines. The bills, of course, include the production and scrapping of batteries. Precisely because of their concern for the environment, Mazda does not intend to put a battery with a capacity of 95-100 kWh on its first electric car MX-30, but equips it with a battery with a capacity of 35.5 kWh, which will not harm the environment so much.

By 2020, Hyundai Motor will provide more than 80,000 zero-emission vehicles to European customers, including Kona Electric, IONIQ Electric and NEXO. This will make Hyundai Motor the largest supplier of EVs in Europe in 2020. Incidentally, on August 19, 2020, the international press reported that the serial electric vehicle Kona Electric with a battery capacity of 64 kWh set a world

record for maximum mileage with a single charge of 1026 km during a three-day test on the German track Lausitzring. Hyundai Kona won the ranking for the most profitable EV in Bulgaria in 2019. It is the best in terms of 'price - mileage with one charge - power'.

Otherwise in Bulgaria, according to the Traffic Police as of October 14, 2020, the number of registered fully electric cars is 1692. An Association of owners of electric cars in Bulgaria has been established [9]. In Bulgaria there are tax reliefs for EVs, which especially in Sofia and most cities do not pay for parking in the so-called BLUE (set aside for parking in the central parts) and GREEN ZONE (with a wider range, outside the BLUE ZONE). No preference is provided for hybrids at this time. It is an interesting fact that in the city of Varna (the third most populous city in Bulgaria) the municipal authorities have provided 22 free charging stations for owners of EVs with two charging points each, and for the period September 18, 2020 - October 31, 2020 the number of EVS charges is 1693 and the reported electricity consumption is 10492 kWh. The ultimate goal is to stimulate the use of environmentally friendly vehicles and improve the cleanliness of the air in the city.

Electricity really pays off. The benefits include low total operating costs and low servicing costs. Maintenance, as suggested by the EV system itself, is significantly more limited than that of internal combustion engine (ICE) cars, mainly due to the lack of an exact engine. Regenerative braking significantly reduces brake system wear. In addition, additional benefits are available, such as exemption from parking fees and additional space for EVs in urban areas. A separate issue is the demonstration of an ecological way of thinking and the request for association with similar type of initiatives, such as the use of EV.

It is generally agreed that the problem with the price of EV will be solved in a few years, taking into account two factors: the inevitable reduction in the cost of series production and the rapid development of technology. To solve the second problem, it is vital to create an appropriate charging infrastructure. Efficient, easily accessible charging stations with wide charging possibilities are needed. Currently, most of the available EVs are charged at home during the time when they are not moving. Therefore, when traveling longer distances, it is necessary to study in advance and plan the possibilities for recharging. In general, customers who want to buy an EV face a complex dilemma: either pay more for a large battery, or charge more often. The price of EVs continues to be significantly higher than that of cars in the same segment and class, as the value is determined mainly by the battery, which depends on how much mileage will be on a single charge. Respectively, the better the characteristics, the more expensive the electric vehicle. Practical research, development, testing and production are currently aimed at improving the volumetric energy density of battery cells (more kilowatt hours for the same volume).

Mileage is influenced by factors such as road characteristics, weather conditions, driving style and additional load (air conditioning and heating system). The stage of the load cycle, potential, local concentration, temperature, and direction of the current all affect the aging and degradation of a battery cell [10]. According to some opinions, 3 factors are important for EVs – space, weight and efficiency.

In order to promote the use of environmentally friendly transport, and in particular of hybrid and fully electrified vehicles, both for consumers and vehicles, it is necessary to build infrastructure for charging stations. Electric vehicles charging stations are complex systems. Charging stations in workplaces or public places support the market acceptance of electric vehicles. Charging time varies depending on the energy content of the battery, its type, and the type of supply equipment. Charging time ranges from 15 minutes to 20 hours or more, depending on these factors. In addition to cable charging, inductive charging is also possible: inductive charging equipment uses an electromagnetic

field to transmit electricity to the EV without the help of a cable. Electric vehicles that are currently available do not use inductive charging, but a standard is being developed that is likely to be applicable in the future. Perhaps the most complex are precisely the non-contact or inductive contact points. They use the principle of transformer or electromagnetic induction. Generally speaking, half of the transformer for transferring energy for charging is installed in the EV, and the other half – in the contact point. There is a mechanism for accurate and automatic adjustment of the two halves of the energy transfer transformer. The huge advantage is that there is no cable connecting the EV to the contact point, but the system is complex and can have significant transmission losses.

The crucial importance of electrical connectors for providing a connection has led to the development of many standards and other documents that describe their electrical and mechanical properties and tools for testing and certification. They are relatively expensive elements of the electrical and electronic installation of any system and largely determine its reliability. The manufacturer usually guarantees at least 10,000 switching on and off between the socket and the plug. With an average of three starts per day, this means that the plugs will be able to be used in normal operation for about 111 months, which is good reliability.

Externally installed charging stations in use are safe even if the vehicle is charging in the rain. The installation of chargers for EVs must comply with national and international laws and regulations. Permission for such installation must be obtained after fire, electrical and environmental inspection.

There are several directions in which charging stations for EVs are developing. On the one hand, they are working to increase their power and the ability to charge several vehicles at the same time, and on the other hand, various methods are being developed for more convenient management of charging stations and the use of different payment methods when they are installed for commercial purposes.

Usually during the working week personal cars are used for 0.5 - 2 hours before the working day and 0.5 - 2 hours after its end. They spend 8-9 hours a day in the parking lot in front of the workplace and this creates conditions for recharging the EVs battery. It is clear that in urban and suburban use of the EV, charging and recharging the batteries is not a problem. Of course, the charging station requires a certain initial investment. A well-made and maintained charging station can then function for many years, as it is an electronic device that wears very little. This makes such an investment justified. Given that most batteries use the accumulated energy only at 55-80%, it can be calculated how long they will have to charge if they are completely exhausted. Therefore, it is assumed that users of EVs will have to recharge them at every opportunity, without waiting for full discharge, which usually shortens battery life.

Charging at home at a night rate costs in Bulgaria about 0.125 BGN / kWh or about 2.30 BGN per 100 km. The daily tariff is almost twice as expensive and this is one of the reasons why it is recommended to charge an EV at night. By the way, according to Eurostat data from November 2019, Bulgarian households pay for the cheapest electricity in the EU, as the average price is 9.9 eurocents per kWh, while the average level in the EU is 21 eurocents. The most expensive is electricity in Germany - 30.9 euro cents and Belgium - 28.4 euro cents. Charging of public charging stations varies from free (in order to attract customers to a commercial site or with incentives through public funds) to 0.55 BGN / kWh (about 9-10 BGN / 100 km). Kaufland maintains an infrastructure network of completely free, fast-charging 50 kW DC power stations, accessible to all in a number of its parking lots across the country. This is part of the company's vision for a modern and green urban environment with the environment in mind. The stations can charge two EVs at the same time. The investment for each charging station is about 80,000 BGN.

Significant efforts are being made to harmonize terminology and develop common standards and systems applicable to all electric vehicles, hybrid vehicles and charging stations. There is still much to be desired, as there is no universal standardization even at the level of the electrical network, both in voltage (110 V, 117 V, 220 V, 240 V, etc.) and in frequency, direct current, 50 Hz, 60 Hz, 400 Hz), conductors, current thresholds, types of contact points and other basic elements of the mass electricity distribution network.

The main organizations that deal with the clarification of terminology and development of standards in this area are SAE International (SAE - Society of Automobile Engineers) and the International Electrotechnical Commission (IEC). Some of the standards in this field are SAE-J1939, JVES G105, UL2251, SAE-J1772, IEC60309, IEC61851, IEC 62196 and others.

Technical features and trends for EV charging stations are discussed in [11], and the situation in Bulgaria - respectively in [12].

Different brands of EVs with different technical characteristics are produced in the world. There are several problems: slower entry of technology, thanks to the fact that quotas for EVs go more to more developed markets such as the Netherlands and Norway, and when there are no EVs, there is no way for the accompanying infrastructure to develop so quickly.

The on-board chargers, which are built into the EVs themselves, work effectively only at a certain charging speed. Every car manufacturer describes this optimal charging speed necessary for the efficient operation of the on-board charger. The charging time of the EV depends on the power of the on-board charger and the charging station. Changes in ambient temperature can also affect the behavior and performance of power supplies, making understanding the power supply's operational temperature range crucial to the reliability.

Attention should be paid not only to the mileage and efficiency of the EV itself, but also to the efficiency of its charging system. Batteries from older lithium-ion technologies suffer from the 'memory effect', which is currently being overcome, meaning that the battery of the EV can be partially charged as often as you want, without leading to its premature damage. How long a battery will last depends a lot on the way the car was driven by the original and each subsequent owner. Analysts believe that EVs will soon become the largest consumer of lithium-ion batteries - a position that is currently occupied by the consumer electronics sector.

Experts from the Canadian company Geotab, specialized in the management of car fleets with systems for global positioning and follow-up have calculated the speed at which batteries of electric vehicles lose the capacity. The study included 6,300 EVs from various brands around the world. According to the authors of the study, batteries lose an average of 2.3% of their capacity per year. For example, with an EV with a mileage of 150 km in 5 years, this mileage will decrease by 20 km. However, Geolab has argued that the depreciation rate depends to a large extent on the characteristics of the cooling system. Canadians note that the decline in battery efficiency may be non-linear - low losses at the beginning are sometimes followed by a series. The charging speed also affects the battery life [13]. In general, for comparison - the loss of mobile phones is 4% per year. Battery life depends mainly on the number of charge / discharge cycles, not just the years of operation.

As is well known, the rechargeable battery is the main source of electricity for driving EVs and for ensuring the normal operation of all on-board devices and systems. After running out of electricity, it must be recharged. Recharging the battery means restoring its initial electric charge and, consequently, the energy capability of the EV. In "pure" EVs, this is done technologically with electric current by connecting to an external source of electricity [14].

Usually the on-board charger (OBC) is part of the EV and is single-phase - with up to 3.7 kW power or three-phase device with 11 kW power. It should be borne in mind that the possibility of

charging is determined by the weakest link in the circuit (the mains socket, cable or power supply used). Another feature is that when charging high-voltage batteries, their maximum capacity (State Of Charge, SOC) must not be reached in order to be able to recharge when stopping or descending, ie. in recuperation. The available capacity is limited via a state-of-charge buffers by a software way, thus reducing mileage, but the rechargeable batteries last much longer.

Modern EVs, with few exceptions, support two types of charging:

A) AC Charging. AC charging speed is slower than DC charging speed. Usually this is how an EV is charged while it is parked in the garage, on the street, in front of the office, in front of the cinema, in the parking lot in malls, etc. In this way, although charging is slower, it practically does not take any time for the user. Slow charging is much more gentle on the battery, extends the life of the EV and is recommended for everyday use. Typically, EVs sold in Europe have a standard AC port known as Type 2. AC charging uses an on-board charger that is integrated into all EVs. It dissipates the incoming alternating current and converts it to direct current, with a conversion loss of up to 10%. One of the main parameters when choosing an EV should definitely be the power of the built-in (integrated) charger, which determines how fast it can be charged at much cheaper and much more widespread AC charging stations.

Depending on the capabilities of the charging converter installed in them, the following AC charging capacities can be used for the different models of EVs:

- Charging from a regular mains socket (Schuko type - 230 V). A Schuko-to-Type2 accessory is used, which is usually supplied with the EV. The household contact is familiar to each of us. We include all kinds of household appliances in the socket and usually the charging power from a household socket is up to about 2.5 kW. The short name for household socket, which we have been using for a long time in Bulgaria, is Schuko, which is an abbreviation of the German Schutz Kontakt or grounded socket. The charging power is between 2.3 kW and 3.6 kW and must comply with the electrical installation - wire cross section, curve and switching-off current of the protective fuse.
- Charging from an AC charging station. The charging speed again depends on the EV model. Most often the charging is with single-phase current 32 A, which gives a power of 7.4 kW. Some EV models support three-phase charging from 11 kW to 22 kW. Some charging points have a built-in Type2 cable, while others require you to plug in your own.

B) DC Charging. The possibility of the fastest charging is provided by the direct current (DC) charger. Most DC charging stations today offer power of 50 kW, but there are also those with lower levels - about 20-25 kW. There is currently a need to move to levels of 100-150 kW, even up to 400 kW, to service the next generation of electric vehicles with much higher capacity batteries (80 kWh and more) [14].

A DC charging station gets AC power from the grid and converts it to DC voltage and uses it to charge the battery pack directly by bypassing the On-board Charger (OBC). These chargers normally output high voltage of up to 600 V and current up to 400 A.

The disadvantage of this type of charger is its complex engineering where it needs to communicate with EV to charge it efficiently and safely.

Whatever EV is connected to a DC charging station, the charging speed (power) is the same. The reason for this is that the alternating current from the mains has already been transformed into direct current outside the EV and can be applied directly to the battery. DC chargers are currently only used for public stations, but are an extremely convenient and easy form of charging when the user is in a hurry. It takes up to 75 minutes to charge a high-capacity battery from 0 to 80%. There is also the fact that charging over 80% on a fast charging station is significantly slowed down so

as not to overload and damage the battery. Fast DC charging stations can be found most often on highways, as well as in the parking areas of large retail chains.

In Fig. 1 are shown EV on-board chargers and charging stations.

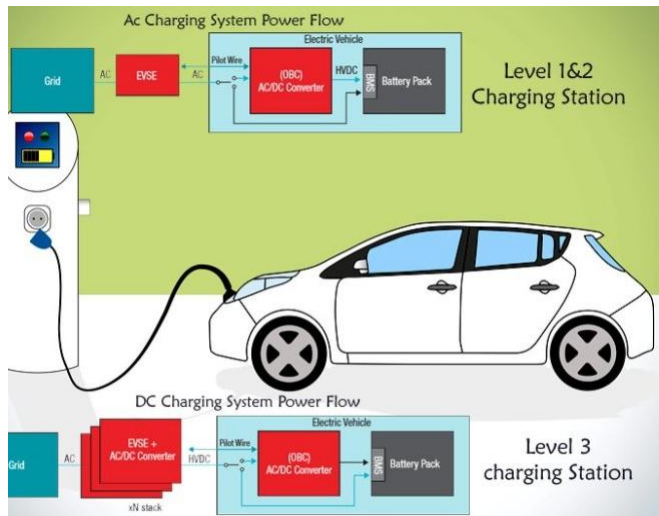


Fig. 1 EV On-board Chargers and Charging Stations [15]

Determining the efficiency of the on-board charger for home 10A charging

Nearly 80% of the owners of EVs charge their batteries at home, and 15% - at place of work.

How is the efficiency of the on-board charger determined? The example given below is for a specific model of EV [16].

Peugeot e-208

- Mileage: 340 km
- Energy consumption: 17.6 kWh/100 km (with charging losses)
- Usable battery capacity: 46 kWh

First we calculate the Energy consumption without charging losses.

340 km → 46 kWh

100 km → X

$X = 46 \times 100 \div 340 = 13.53 \text{ kWh/100 km}$

Now, if we divide this number by 17.6 kWh / 100 km, we get the efficiency of the on-board charger.

$Y = 13.53 \div 17.6 = 0.76875 \approx 77\%$.

This is how the efficiency of the on-board charger is calculated. We remind you that these are results when charging with the largest losses, namely from household contact with a current of 10 A. When charging with 32 A (per phase) from a charging station, the results are much better.

3. Results and findings

The advantage of an AC charging station is that the on-board charger will regulate the voltage and current as required for the EV hence it is not mandatory for the charging station to communicate to the EV.

Results obtained for single-phase EVs available on the market are presented in Table 1, and for three-phase EVs - in Table 2, respectively. The information applies to BEV - battery-powered electric vehicles - electric vehicles that are powered only by an electric motor(s) and powered only by a battery, usually lithium-ion and PHEV - Plug-in Hybrid Electric Vehicles, which are equipped with two the drives - electric and ICE and the batteries can be charged directly from the mains, as well as from ICEs. Regarding

the battery pack capacity, the actual available one is indicated, not the nominal one.

The basic information is provided by [16] and additionally data are collected from publicly available sources - official car manufacturers, their representatives and dealers. A column can be added for the consumption of electric vehicles, defined as kWh / 100 km or € / 100 km, as well as for the mileage with one charge. However, this would make the created tables unnecessarily bulky and heavy.

Table 1: Charging time at 22 kW AC charging station of single-phase electric vehicles

Car brand/model	Type	OBC Power, kW	Battery pack capacity, kWh	Charging time, h
1	2	3	4	5
BMW i3 until mid-2016	EV	7.4	18.8	2.5
BMW i8	PHEV	3.7	10.4	3
BMW 225xe Active Tourer	PHEV	3.7	10	3.2
BMW 530e Sedan/xDrive Sedan	PHEV	3.7	12	3.6
BMW 745p/745Le/Le xDrive	PHEV	3.7	12	3.6
BMW X1 xDrive25e	PHEV	3.7	34	3.2
BMW X2 xDrive25e	PHEV	3.7	34	3.2
BMW X5 xDrive45e	PHEV	3.7	24	6.8
Chevrolet Bolt 2019	EV	7.4	60	8
Citroen C-ZERO	EV	3.7	14.5	4
DS 3 Crossback E-Tense	EV	7.4	47.5	7.5
FIAT 500e USA until 2018	EV	6.6	24	3.5
FORD MUSTANG MACH-E	EV	7.4	70	11
HONDA E	EV	6.6	32	6
Hyundai IONIQ Electric	EV	6.6/7.2	28/38.3	4.5/6
Hyundai IONIQ Plug-in Hybrid	PHEV	3.3	7.1	3
Hyundai Kona until March 2020	EV	7.2	39/64	5.5
Jaguar I-Pace	EV	7.4	84.7	11.5
KIA Soul II EV until 2018	EV	6.6	27	n.a.
KIA Soul EV 2 after 2019	EV	7.2	39.2 / 64	6.5/10.5
KIA e-Niro until June 2020	EV	7.4	64	9
KIA NIRO Plug-in Hybrid	PHEV	3.3	7.1	3
Lexus UX300e	EV	6.6	54.3	n.a.
MAZDA MX-30	EV	6.6	32	6
MG ZS EV	EV	7.4	44.5	6.5
Mercedes-Benz EQC 2019	EV	7.4	80	13
MERCEDES E 300	PHEV	7.4	10.8	2
Mini Countryman	PHEV	3.7	6.5	2
Mitsubishi iMiEV	EV	3.7	14.5	4
Mitsubishi Outlander	PHEV	3.7	13.8	3.5
Nissan LEAF 1 2011-2017	EV	3.3-6.6	38	6
Nissan LEAF 2 2018~	EV	6.6	60	9
Nissan E-NV200	EV	6.6	40	7.5
Opel Corsa-e 2020	EV	7.4	47.5	8
Opel AMPERA-E	EV	7.4	58	8
Opel VIVARO-E	EV	7.4	50/75	8/12
PORSCHE CAYENNE E-HYBRID	PHEV	3.6-7.2	12	4
PORSCHE PANAMERA E-HYBRID	PHEV	3.6-7.2	12	4
PEUGEOT E-2008 SUV	EV	7.4	47.5	7.5
Peugeot e-208	EV	7.4	47.5	7.5
Peugeot iOn	EV	3.3	14.5	4/6
Renault Kangoo ZE	EV	7.4	31	4
SEAT MII ELECTRIC (MODEL 2020)	EV	7.2	32.3	5.5
SEAT el-Born	EV	7.2	62	n.a.
SKODA CITI GO E IV (MODEL 2020)	EV	7.2	32.3	5.5
THINK CITY	EV	3.7	23	8
TOYOTA PRIUS	PHEV	3.3	7.0	2.5
Volkswagen e-Golf	EV	7.2	32	5.34
Volkswagen e-Up! 2011	EV	3.7	16	4
Volkswagen e-Up! 2020	EV	7.2	32.3	5.5
Volkswagen Passat	PHEV	3.7		2.75
Volvo XC90, XC60, V90, S90, V60, S60	PHEV	3.7	9.9	3
Volkswagen ID.3	EV	7.2	45	7.5

Table 2: Charging time at 22 kW AC charging station of three-phase electric vehicles

Car brand/model	Type	OBC Power, kW	Battery pack capacity, kWh	Charging time, h
Audi e-tron Quattro Sportback 50	EV	11	64.7	n.a.
Audi e-tron Quattro Sportback 55	EV	11	86.5	11.5
BMW i3 after July 2016	EV	11	37.9	5
BMW i3 after January 2020	EV	11	74	12
Jaguar I PACE	EV	7/11.	90	12.7/8.5
KIA e-Niro after June 2020	EV	11	n.a.	n.a.
Mercedes-Benz B-Class ED until 2017	EV	9.6	28	n.a.
Mercedes-Benz EQA after 2020	EV	11	60	11
Mercedes-Benz EQV after 2020	EV	11	90	13
MINI COOPER SE	EV	11	28.9	5
Mustang Mach-E SR/ER	EV	11	70/90	12/13
POLESTAR 2 (Volvo)	EV	11	75	12
Porsche Taycan	EV	11/22.	71/83.7	11/13.5
Renault ZOE	EV	22	41 / 52	5.5 / 8.5
Skoda Vision IV	EV	11	83	13
Smart EQ	EV	22	16.7	3.5
Tesla Model 3 (European)	EV	11	62	8
Tesla Model S (European)	EV	16.5	95	14
Tesla Model X (European)	EV	16.5	95	14
Tesla Model Y	EV	11	74	12
TESLA CYBERTRUCK SINGLE MOTOR	EV	11	100	16
Volkswagen ID.3	EV	11	58/77	11/12
Volvo XC40 EV	EV	11	75	12

How long do some EVs charge "fast":

- Nissan claims that the LEAF Plus battery is charged to 80% in 60 minutes from 50 kW charger or for 40 minutes at 100 kW;
- Hyundai Motor states that Kona Electric reaches 80% of the battery charge in 75 minutes at 50 kW or for 54 minutes at 100 kW;
- Jaguar Land Rover claims that the I-Pace charges up to 80% in 40 minutes at 100 kW;
- Audi says that the e-tron's battery can be charged up to 80% in just 30 minutes, but with a 150 kW charger.
- Mercedes-Benz claims that its EQC model is charged at 80% in 40 minutes at 110 kW, but not from scratch, but from 10%.

Of course, all these results have been obtained in the laboratory conditions and do not take into account many factors that can occur in everyday life (air temperature, battery condition, etc.), but still give some idea of the charging speed.

Fig. 2 presents the personal EV of the first author.



Fig. 2 The personal EV of the first author

4. Conclusions

The results obtained could be of great practical importance when someone decides to buy an EV or to build a charging station

by offering the charging service. Statistics are a good guide and help to make the right investment and marketing decisions.

On-board chargers are an important component of EV electrical equipment. The overall behavior of the vehicle during charging periods between service intervals depends on their normal operation.

As with most of the technologies that are just entering our daily lives, EVs are no exception and there are many myths and misconceptions about them.

Electric vehicles will change the purity of the air in cities, i.e. the environment in which people find themselves on a daily basis. We all want to breathe cleaner air. In addition to reducing carbon dioxide emissions and pollution from noise and noise, dependence on imported hydrocarbon fuels is also reduced and the energy security of individual countries is increased. Another benefit is the wider use of renewable energy in transport, the creation of "smart grids", the integration of EVs in them, the increase in the efficiency of conventional power plants and the development of the respective national electricity system. Active community action is needed, including the potential of all experts and supporters, for the development of the new economic sector - electric mobility. In this regard is the construction of sustainable educational models, i.e. changes in the education system in terms of vocational education and training in this area. This is necessary to prepare the necessary staff - technician and electrician of EVs in high school, engineers, bachelors and masters in universities. Doctoral studies have already been introduced in the specialty.

Electric vehicles are still a novelty for the Bulgarian reality - they are below 1%, but the awareness that this is a more efficient and environmentally friendly future of transport is growing. Reducing air pollution is one of the most important priorities we must set as citizens and as a society. This is linked to a long-term electrification strategy, which requires daily efforts to catch up by disseminating information and offering services.

Electric vehicles are the cars of the future and are a solution for a cleaner planet, easier and cheaper to move, especially in an urban environment, where the advantage is easy parking. No one can say how long the transition to EVs will take - the transition to electric drive will depend mainly on consumer interest. Or maybe EVs are just a temporary (transitional) solution. No wonder the technology of the future is different. Perhaps.

Acknowledgments

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Lateral tilting in road vehicles - a review

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Abstract: This paper considers various examples of lateral tilting of road vehicles when cornering. Narrow tilting three wheeled vehicles are considered. Four wheeled tilting small road vehicles, passenger cars with active anti-roll bars and cars with active tilting when moving in a turn are presented. The advantages and disadvantages are discussed.

Keywords: LATERAL TILTING VEHICLES, ACTIVE TILTING, SMALL ROAD VEHICLES, TURN

1. Introduction

When the vehicles move in a bend, a centrifugal force is created, which leads to reduction the comfort of the passengers and the stability of the vehicle. Tilting in land vehicles is being used for the first time in trains. This improves passenger comfort and increases cornering speed. In road vehicles, the principle of tilting is introduced later - in three-wheeled and four-wheeled narrow vehicles, and recently is discuss the use in normally wide passenger cars. The paper will discuss some examples of the applications discussed above and discuss their advantages and disadvantages.

2. Narrow Tilting Three Wheeled Vehicles

Three wheeled vehicles or tri-cycles have better static stability than two-wheelers (motorcycles and mopeds), but poorer dynamic stability when cornering. This is due to the fact that they are usually narrow-gauge and have a relatively high center of gravity. To improve stability, three wheeled vehicles can be provided with a tilting system [1]. Tilting can be done by the driver as in motorcycles or automatically.



Fig. 1 Toyota i-Road [<https://www.autocar.co.uk>].



Fig. 2 Carver One [<https://insideevs.com>].

In Fig. 1 is shown a three wheeled vehicle with two front and one rear wheel, and the vehicle shown in Fig. 2 has two rear and one front wheel.

The advantage of the first option is that there is no need to use a differential. In addition, the driver has visibility for the gauge, as the vehicle is wider at the front. While the second option should use a differential for the drive wheels, but at the expense of simplifying the steering mechanism, which is of the motorcycle type.

Recently, there has been a trend to apply the first scheme to mopeds and motorcycles (see Fig. 3 and Fig. 4). This improves their

static stability and stability at low speeds. The handling is also improved, especially in poor road conditions and low friction or uneven terrain.



Fig. 3 Piaggio MP3 Sport [<https://www.piaggio.com>].



Fig. 4 Yamaha NIKEN GT [<https://www.yamahamotorsports.com>].

Because the front wheels are not wider than the handlebars they are still classified as a motorcycle not tri-cycles [2].

3. Four Wheeled Tilting Small Road Vehicles

These vehicles belong to the group of small city cars. Especially popular in major European cities with high traffic. They are above 50cc and speed not exceeding 45 km/h, and a weight of no more than 550 kg. They can drive with a B1 driver's license from persons over 17 years of age. They have small dimensions and do not require much parking space. The disadvantage is their lower lateral stability due to the narrow track and high center of gravity. To improve cornering stability, some manufacturers offer tilting vehicles of this type. There are also those with electric drive (Fig. 5).



Fig. 5 Nissan Land Glider [<https://newatlas.com>].

This scheme is also available for all-terrain vehicles (ATVs). In this way, both their cornering and lateral slope stability and their passability when driving on uneven terrain are improved (Fig. 6).



Fig.6 Self-balancing ATV [<http://www.carver-technology.nl>].

4. Passenger Cars With Active Anti-Roll Bars and Tilting Cars

In full-size passenger cars of a higher class, active lateral stabilizers are now common, which counteract the centrifugal force and reduce or eliminate the body tilt it causes (Fig. 7).

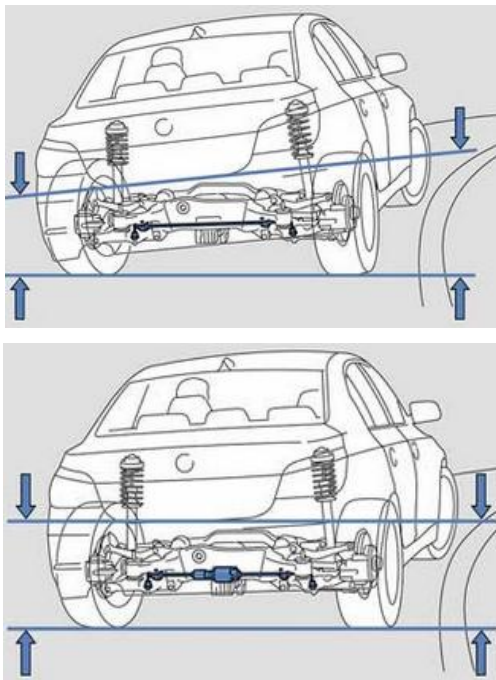


Fig. 7 BMW Dynamic Drive [3].

Active anti-roll technology is increasingly commonplace, mostly using active anti-roll bars that torque themselves up with hydraulics or electric motors to resist lateral forces, softening off again for the improving of comfort when the car is back in a straight line.

Mercedes' curve tilting function takes this process to the next level and instead anti-roll bars, they actively raise the suspension spring platforms on the outside of the turn and lower them on the inside, creating an effect resembling motorcycle driving [<https://www.carmagazine.co.uk>]. The curve tilting function can be selected using the three-position ABC switch, and is active in a speed range of 15 to 180 km/h in "Curve" mode. Further selection options include "Comfort" (Magic Body Control with Road Surface Scan) and "Sport" [<https://media.daimler.com>]. Integrated closely with the Active Body Control (ABC) and Road Surface Scan functions of Magic Body Control, the new feature uses suspension

struts which are equipped with hydraulic cylinders that can make the car automatically incline in a fraction of a second and to an angle of up to 2.5 degrees in curves [4]. It can be seen in Fig. 8.

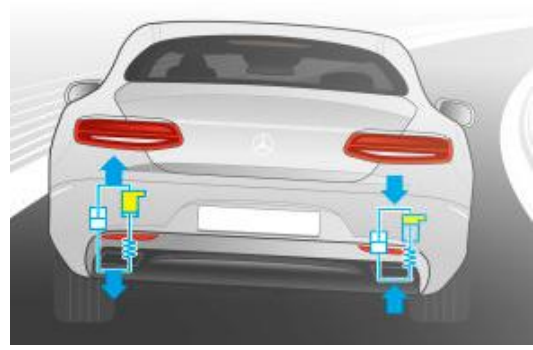


Fig. 8 Mercedes-Benz S-Class Coupe, Active Body Control, curve tilting function [<https://media.daimler.com>].

The four suspension struts are equipped with hydraulic cylinders, in order to adjust the force in each strut individually. The control unit receives information on the current driving situation from various acceleration sensors, level sensors on the control arms and driving speed. The system then calculates the control signals for the servo-hydraulic valves on the front and rear axle by means of the pressure sensors in the spring struts to ensure suitable proportioning of the oil flows [<https://media.daimler.com>].

5. Conclusions

The shown technologies are for tilting the chassis of the vehicles. Narrow tilting tricycles and quadricycles can achieve greater tilt angles than passenger cars. In order to achieve a greater reduction in lateral acceleration, additional seat tilting should be applied to them or only the seats should be tilted on their own [5]. However, this is associated with other inconveniences, such as additional mechatronic systems located in the car body, lack of sufficient space for tilting - especially in the rear seats, problems with perceptions and feedback from the driver on the allowable speed in corners and so on.

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Some requirements to the mechanisms of handling machines for dangerous goods and solutions for their satisfaction

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Abstract: The article reviews the requirements for the lifting mechanisms of cranes according to various regulations concerning dangerous goods. Particular attention is paid to these requirements regarding gear trains. Some design solutions for providing microspeed as well as for twin-motor drive are discussed. These arrangements are suitable for both lifting and travel mechanisms. A kinematic analysis was made and recommendations were given to the designers.

KEYWORDS: CRANES, DANGEROUS GOODS, GEAR TRAIN, HANDLING MACHINES

1. Introduction

In addition to the universal requirements for handling (lifting and transport) machines (HM), HM for dangerous goods (hot molten metal, containers with chemicals, explosives, etc.) must also meet a number of special requirements. These requirements can be found in the relevant regulations, such as the regulations of the State Agency for Metrology and Technical Supervision [16, 17] and various national and international standards [1, 2, 6, 7, 8, 9, 10, 12]. There are also good practices that manufacturers adhere to, even though they are not regulated [18].

Some of these requirements concern the machine as a whole (seismic resistance, elevated safety factors and requirements for the reliability of the parts, etc.). Others refer to the individual mechanisms or their units and assemblies.

BDS 8916-81 [6] stipulates that the group of working modes (duty) of load lifting mechanisms and jib lifting mechanisms for cranes transporting molten metal or slag, toxic, explosive substances and other dangerous goods must be not less than 5, except for self-propelled jib cranes, for which it must be not less than 3.

This requirement does not apply to auxiliary lifting mechanisms if they do not take part in the transport of the above loads. In the absence of specific data for determining the class of use and the load factor, it is allowed to determine the group of the operating mode from a table listing the different types of cranes and their mechanisms (main and auxiliary lifting, trolley and crane movement, rotation, range change and other mechanisms). In this table, the recommended working mode of the main lifting mechanism for most metallurgical cranes (with forks, mold, multi-magnetic, multi-grapple, for loading furnaces, stripper, shaft, clamps) is very heavy (6th group), whereas for hardening, foundry (casting), and forging crane - heavy (5th group).

In BDS ISO 4301-5 [9] there is no special text for cranes for dangerous goods, but in the table with instructions are assigned the highest classification groups - A7 and A8 for the crane and M7 and M8 for the mechanisms. The classification of bridge and gantry cranes and their mechanisms, depends on the use of the crane for cranes in steel mills (Table 1). Exceptions are only the cranes in the rolling mills (A2, M3, and M4 respectively).

Irrespective of the mode of operation in the strength calculation of the hoists of cranes for molten metal or slag, poisonous and explosive substances, a safety factor of not less than 6 must be used (as for very heavy-duty operation of cranes and jib cranes). Moreover BDS 15164-80 [7] obliges protection with fences of the ropes of cranes carrying molten metal or liquid slag from the direct action of heat and splashes of metal.

According to BDS 16879-88 [8] during changing the range and traveling of the cranes and trolleys with inclined railroads, intended for transportation of molten metal or slag, poisonous or explosive substances and other dangerous goods, the use of friction and thumb couplings in lifting mechanisms is not allowed.

Another requirement is that the lifting mechanism must have two brakes – working and locking (activated after stopping the mechanism) [13, 15].

Table 1. Guidelines for classification of bridge and gantry cranes and their mechanisms depending on the use of the crane (extract from BDS ISO 4301-5 for a crane in a steel foundry)

Crane type	Crane classification group as a whole	Classification group of the mechanism as a whole		
		Lifting	Trolley traveling	Crane traveling
Crane in a rolling mill	A2	M4	M3	M4
Foundry (casting) crane	A7	M8	M6	M7
Shaft crane	A7	M8	M7	M7
Stripper crane	A8	M8	M8	M8
Furnaces loading crane	A8	M8	M8	M8

In the framework of a research contract with UCTM-Sofia, the authors have examined only those requirements that concern the gear trains of the mentioned mechanisms:

1. Provide a microspeed (slow speed) of the lifting mechanism, in accordance with the specifics of the processed dangerous goods.
2. Driving the mechanisms with two engines (motors), which are able to work independently in case of emergency (failure of one engine). This is especially important in metallurgical machines working with molten metal. If one engine fails, the other must be able to complete the operation so that the metal does not freeze in the bucket.

This article presents some solutions that meet the first requirement, in which a single-carrier planetary gear train (PGT) of the most often used type – $\overline{AI}$ -planetary gear train is involved (**Fig. 1**).

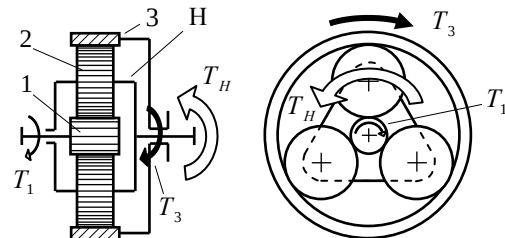


Fig. 1. The most often used type planetary gear train – $\overline{AI}$ -PGT with one-rim planets with one external and one internal meshing

2. $\overline{\text{AI}}$ -Planetary Gear Train and its Possibilities

2.1 Arrangement of $\overline{\text{AI}}$ -Planetary Gear Train

This type of most often used negative-ratio ($i_0 < 0$) planetary gear train (PGT) (Fig. 1) is signified in different ways. is signified in different ways. In many countries the Kudryavtsev's designation 2K-H is popular. It means two central gears (2K) and a carrier (H). In this article Prof. Tkachenko's designation is used [3, 4] as more detailed one (A for external and I for internal meshing, overline for one-rim planet).

As shown in Fig. 1 this gear train has two central gear wheels – a sun gear 1 with external teeth and a ring gear 3 with internal teeth. These two gears 1 and 3 mesh with one-rim planets 2 which are housed in carrier H. Their number most often is $k=3$, more rare $k=2$ or 4, but in special cases there are PGTs with $k=20$ planets [3, 4]. However, planets number k does not affect the gear train's kinematics. Increasing the planets number ($k > 1$) because of the torque sharing, leads to a few effects:

- Decreasing the overall dimensions and mass of the gear train;
- Decreasing the mesh load;
- Unloading the central element bearings – sun gear 1 and carrier H;
- Decreasing the noise level because of the lower peripheral velocities and higher accuracy of the smaller gears.

Central elements of the gear train (sun gear 1, ring gear 3 and carrier H) rotate around an axis – the so called *main (central) geometrical axis of the gear train*. Typical of this simple PGT is that there are three shafts that go out of the train (external shafts). In Fig. 1 the corresponding external torques T_1 , T_3 , and T_H also are shown. Two of them T_1 and T_3 are unidirectional, and the third torque T_H is with opposite direction. Since the train is simple, of course, it has only one carrier, i.e. it is a single-carrier PGT.

2.2 Possible Ways of Working of $\overline{\text{AI}}$ -planetary gear train

This train, like other PGTs, can operate both with $F=1$ and $F=2$ degrees of freedom. With $F=1$ degree of freedom any one of three shafts (of the sun gear 1, ring gear 3 or carrier H) can be fixed. In Fig. 2a and 2b the six possible working modes in this case are shown – three modes as a reducer and three modes as a multiplier.

Input power is denoted with P_A and output – with P_B . With a fixed carrier ($\omega_H = 0$), the PGT works as pseudo-planetary. At $F=2$ degrees of freedom (working as differential), six working modes are possible, too (Fig. 2c and 2d) – three as a summation PGT and three as a division PGT.

The kinematic analysis of this gear train– the determination of speed ratios when working with $F=1$ degree of freedom or speeds of the input shaft(s) in case of $F=2$ degree of freedom is made through the basic speed ratio i_0 – the ratio of the pseudo-planetary gear train working as reducer with fixed carrier ($\omega_H = 0$)

$$i_0 = i_{13(H)} \quad (1)$$

The speed ratios in the other cases of work with $F=1$ degree of freedom (Fig. 2a and 2b) are expressed through it [3, 4].

Formula (1) applies to all types of PGTs. For the $\overline{\text{AI}}$ -PGT considered here, basic speed ratio depends on number of teeth of the sun gear Z_1 and the ring gear Z_3 [3, 4]

$$i_0 = -\frac{Z_3}{Z_1} \quad (2)$$

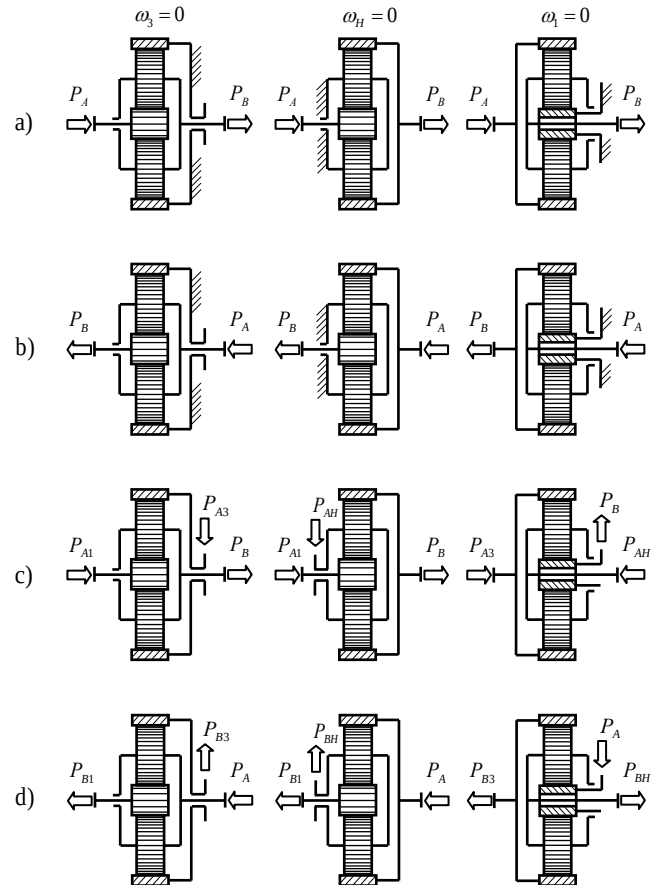


Fig. 2. Working modes of $\overline{\text{AI}}$ -planetary gear train [3, 4]:

With $F=1$ degree of freedom:

a) as a reducer (reduce the speed);

b) as a multiplier (multiply the speed).

With $F=2$ degrees of freedom (i.e. as differential):

c) as a summation PGT;

d) as a division PGT.

The above-mentioned advantages and capabilities are used in the mechanisms discussed in the article.

3. Microspeed providing

The lifting (hoisting) mechanisms of the cranes usually provide a microspeed around 20 - 25% of the main one [11, 14]. This is most easily achieved by changing the number of poles of the electric motor and hence its speed. When the asynchronous motor operates with one pair of poles, the synchronous speed (of the magnetic field) is 3000 min^{-1} , and when it operates with four pairs of poles – 750 min^{-1} . The operating speeds are slightly lower (approx. 2940 or 720 min^{-1}), depending on the power. If the microspeed thus achieved is not low enough, its required value must be achieved by a twin-motor drive and/or a suitable gear train design.

Fig. 3 shows an example of operation of a $\overline{\text{AI}}$ -planetary gear with $F=2$ degrees of freedom, i.e. a differential that performs the summation of two movements from two electric motors [3, 4].

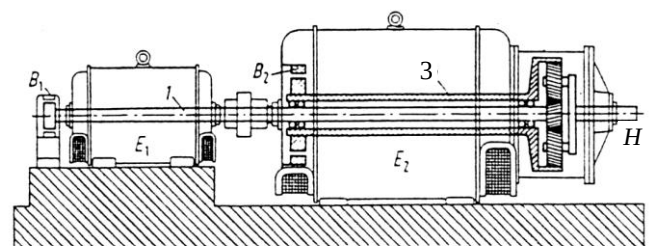


Fig. 3. Twin-motor two-speed drive with an $\overline{\text{AI}}$ -PGT operating as summation differential [3]

Although used primarily to provide microspeed, this arrangement has more scope to achieve more speeds of the output shaft:

1. Only the small motor E_1 is running (the shaft 3 of the big motor E_2 is fixed by brake B_2) – a high speed ratio is obtained (**Fig. 4a**)

$$i_{13(H)} = i_0 = -\frac{z_3}{z_1}; \quad (3)$$

2. Only the big motor E_2 is running (the shaft 1 of the small motor E_1 is fixed by brake B_1) – a low speed ratio is obtained [3, 4] (**Fig. 4b**)

$$i_{3H(1)} = 1 - \frac{1}{i_0} = 1 + \frac{z_1}{z_3}; \quad (4)$$

3. Both motors operate simultaneously in one or in different directions – the obtained speed ratios depend on the basic speed ratio i_0 of the (**Fig. 4c**).

When the arrangement from Fig. 3 is used for two-speed drive (main and microspeed), the PGT operates in both variants in Fig. 4a and 4b.

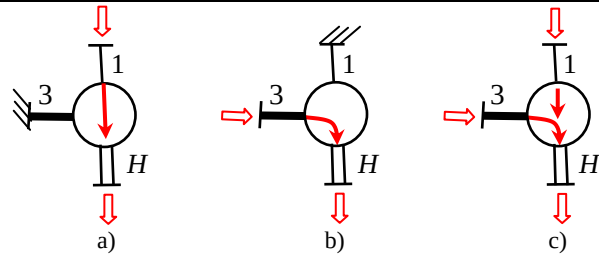


Fig. 4. Working modes of the PGT from figure 3

Some cranes for dangerous goods require the microspeed to be much lower than the main one.

Fig. 5 shows the kinematic scheme of the gearbox (reducer) of a 200-ton container crane for Kozloduy nuclear power plant (NPP), manufactured by “BulmachineryEnterprices” - Radomir [3, 5]. It can perform two speed ratios $i = 141$ and $i_m = 2228$ for fast and slow speed (main and microspeed). In the large gear of the third gear stage a planetary gear train is built-in. The two speed ratios are carried out by operating only one of the motors. At main(fast) speed (Fig. 5a) the large motor is working, which drives the sun gear 1 of the PGT with fixed ring gear 3. At microspeed (slow speed) (Fig. 5b) the small motor is working, the ring gear 3 is driving, and the sun gear is fixed. In both cases, the carrier H is the output of the PGT. In **Fig. 6** the gearbox with removed top is shown.

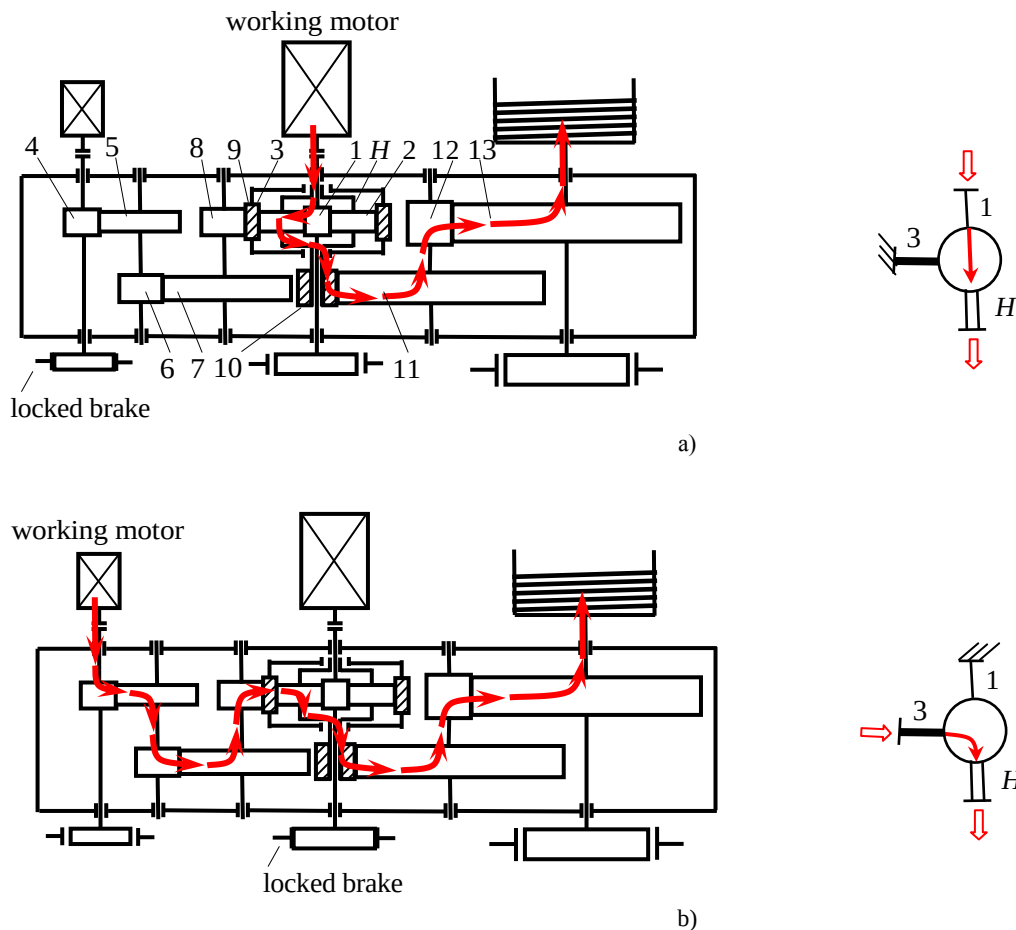


Fig. 5. Operation of $\overline{AI}$ -PGT as a stage of a two-speed gearbox of a hoisting mechanism [3, 5]

a) at main speed, speed ratio $i = 141$

b) at microspeed, speed ratio $i = 2228$



Fig. 6. The gearbox from Fig. 5 [3, 4, 5]

In the gearbox from Fig. 5 the PGT in both cases with $F = 1$ degree of freedom is working. Its speed ratios depend on the basic speed ratio i_0 defined in (2) and when operating at main speed (PGT operates with a fixed ring gear 3) it is

$$i_{1H(3)} = (1 - i_0), \quad (3)$$

and when operating at microspeed (PGT operates with a fixed sun gear 1) it is

$$i_{3H(1)} = 1 - \frac{1}{i_0}. \quad (4)$$

With these values it participates in determining the speed ratio of the gearbox:

• Main speed:

$$i = i_{1H(3)} \cdot i_{10,11} \cdot i_{12,13} = \left(1 + \frac{Z_3}{Z_1}\right) \cdot \frac{Z_{11}}{Z_{10}} \cdot \frac{Z_{13}}{Z_{12}}. \quad (5)$$

• Microspeed:

$$\begin{aligned} i_m &= i_{45} \cdot i_{67} \cdot i_{89} \cdot i_{3H(1)} \cdot i_{10,11} \cdot i_{12,13} = \\ &= \frac{Z_5}{Z_4} \cdot \frac{Z_7}{Z_6} \cdot \frac{Z_9}{Z_8} \left(1 + \frac{Z_1}{Z_3}\right) \frac{Z_{11}}{Z_{10}} \cdot \frac{Z_{13}}{Z_{12}}. \end{aligned} \quad (6)$$

Conclusions

Of the considered requirements for the lifting mechanisms of cranes for dangerous goods, two concern gears:

- Providing microspeed;
- Driving the mechanisms with two motors.

Due to their wide range of capabilities, planetary gears are suitable for embedding into these mechanisms. In the considered two arrangements the property of the most usual used $\overline{AI}$ -PGT to work with one and two degrees of freedom is used.

Acknowledgments

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Reducer with a planetary gear train for a hoisting mechanism of dangerous goods cranes

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Abstract: In addition to the universal requirements for handling (lifting and transport) machines (HM), HM for dangerous goods (hot molten metal, containers with chemicals, explosives, etc.) must also meet a number of special requirements. One of these requirements is the drive of the hoisting mechanism with two motors, to ensure in case one of them fails.

The article discusses a reducer for the hoisting mechanism of an overhead crane for dangerous goods with an embedded planetary gear train, allowing both motors to operate at full power (and without overload) in both regular and emergency (in failure) mode. The different modes of work of the mechanism are considered (with both motors and with each one separately). An analysis of the possible kinematic schemes of the planetary gear train is made. The necessary kinematic calculations have been made to select the most suitable variant of the planetary gear train.

KEYWORDS: CRANES, DANGEROUS GOODS, GEAR TRAIN, HANDLING MACHINES

1. Introduction

Risk management in the transport and handling of dangerous goods has always been relevant [8]. In addition to the universal requirements for handling (lifting and transport) machines (HM) [1, 2, 5, 6], HM for dangerous goods (hot molten metal, containers with chemicals, explosives, etc.) must also meet a number of special requirements [10]. Some of these requirements apply to the machine as a whole [6]. Others refer to individual mechanisms or to their aggregates and assemblies [5].

In the framework of a research project with UCTM (Univ. of Chemical Technology and Metallurgy), the authors have examined only those requirements that relate to the gear trains of the mentioned mechanisms:

1. Ensuring micro-speed of the hoisting mechanism, in accordance with the specifics of the processed dangerous goods.
2. Drive of the mechanisms with two motors, which are able to work independently in case of emergency (failure of one motor) [7]. This is especially important in metallurgical machines working with molten metal. If one motor fails, the other must be able to complete the operation so that the metal does not freeze in the bucket.

This paper examines some solutions that meet the second requirement.

Classic solution: Each of the motors (I and II) is selected with a power of 65 - 85% of the required for the drive of the mechanism, which allows independently, in overload mode, to complete the hoisting operation to the end:

$$P_{AI} = P_{AII} = (0,65 \div 0,85) P_B \text{ and } \omega_{AI} = \omega_{AII}. \quad (1)$$

Disadvantage: In normal operation, each of the motors operates at 77 - 60% of its rated power [9], which leads to lower efficiency.

Rational solution: Gearbox with embedded planetary gear train [3, 4] - each of the motors is selected with a power of 50% of the required and in both regular and failure mode operates at 100% of its rated power:

$$P_{AI} = P_{AII} = 0,5 P_B \text{ and } \omega_{AI} = \omega_{AII}. \quad (2)$$

The considerations here are made for a single-carrier planetary gear train of the most often used type - $\overline{AI}$ -planetary gear train (Fig. 1), but in the process of work a variant with AI-planetary gear train is also considered (Fig. 2).

As shown in Figure 1 these gear trains have two central gear wheels - a *sun gear* 1 with external teeth and a *ring gear* 3 with internal teeth. These two gears 1 and 3 mesh with one-rim or two-rim *planets* 2 which are housed in *carrier* H. Their number most often is $k=3$, rarer $k=2$ or 4, but in special cases there are PGTs with $k=20$ planets [PGT]. However, planets number k does not affect the gear train's kinematics.

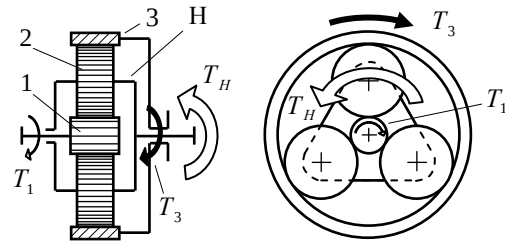
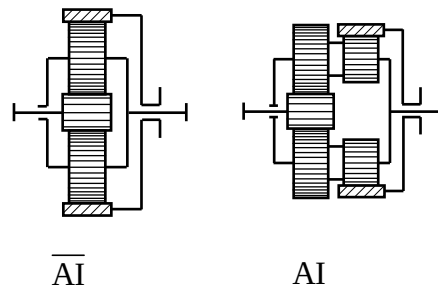


Fig. 1 Most often used $\overline{AI}$ -planetary gear train with one-rim planet with one external and one internal meshing.



$$i_0 = -\frac{z_3}{z_1} \quad i_0 = -\frac{z_3}{z_2'} \cdot \frac{z_2}{z_1}$$

Fig. 2 $\overline{AI}$ - and AI-planetary gear trains and their basic ratio.

Central elements of the gear train (sun gear 1, ring gear 3 and carrier H) rotate around an axis - the so called *main (central) geometrical axis of the gear train*. Typical of this simple PGT is that there are three shafts that go out of the train (external shafts). In Fig. 1 the corresponding external torques T_1 , T_3 , and T_H also are shown. Two of them T_1 and T_3 are unidirectional, and the third torque T_H is with opposite direction. Since the train is simple, of course, it has only one carrier, i.e. it is a single-carrier PGT.

These trains, like other PGTs, can operate both with $F=1$ and $F=2$ degrees of freedom. With $F=1$ degree of freedom any one of three shafts (of the sun gear 1, ring gear 3 or carrier H) can be fixed. With a fixed carrier ($\omega_H = 0$), the PGT works as pseudo-planetary. At $F=2$ degrees of freedom (working as differential), six working modes are possible - three as a summation PGT and three as a division PGT.

The kinematic analysis of this gear train - the determination of speed ratios when working with $F=1$ degree of freedom or speeds

of the input shaft(s) in case of $F = 2$ degree of freedom is made through the basic speed ratio i_0 – the ratio of the pseudo-planetary gear train working as reducer with fixed carrier ($\omega_H = 0$)

$$i_0 = i_{13(H)} \quad (3)$$

The gear ratios of the other cases of work with $F = 1$ degree of freedom (Fig. 2 a and b) are expressed through it [3, 4]. The above possibilities are used in the mechanisms discussed in the paper.

2. Tween-motor driven hoisting mechanism – in regular mode working

Fig. 3 shows the kinematic scheme of the reducer of the main hoisting mechanism of a 190-ton overhead (bridge) crane with embedded planetary gear train. As mentioned above, for high-capacity cranes, twin-motor drive is desirable (and for foundries and dangerous goods in general, it is mandatory). It is made so that if one motor fails, the other is able to complete the necessary movement on its own. Usually, when no differential is used, the two motors drive the input shaft and select the same power and angular velocity, each with a power equal to 65 - 85% of the total required power, so that they can operate independently in failure mode, although and with overload (see formula 1).

In the shown in FIG. 3 arrangement this disadvantage is avoided due to the use of $\overline{AI}$ -planetary gear train. Both motors are selected with the same power $P_{AI} = P_{AII}$ (equal to 50% of the required for the hoisting mechanism) and angular velocity $\omega_{AI} = \omega_{AII}$ and in regular mode (Fig. 3) operate at their rated power

$$P_B = P_{AI} + P_{AII} \quad (4)$$

When both motors are working, the angular velocity ω_H of the carrier H of the planetary gear train is determined by the known formula for summing the motions [3, 4]

$$\omega_H = \frac{\omega_1 - i_0 \cdot \omega_3}{1 - i_0} = \frac{\omega_1 + t \cdot \omega_3}{1 + t} \quad (5)$$

where

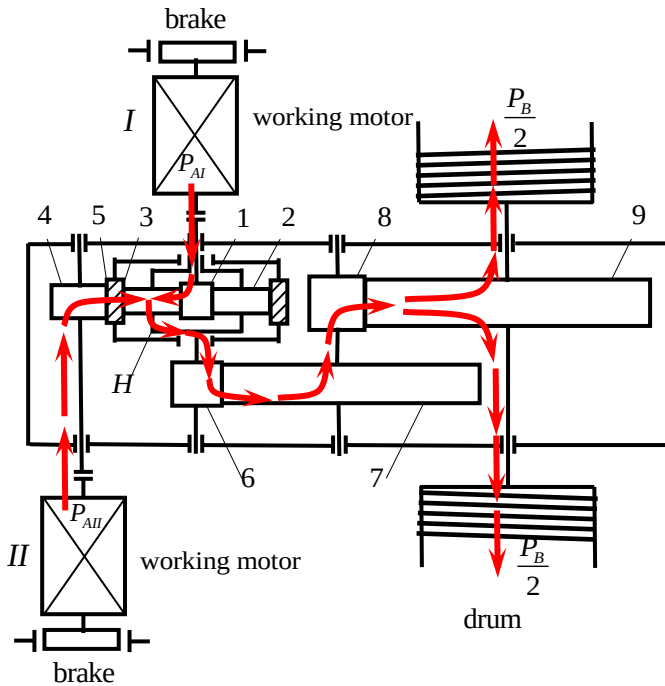
$$\begin{aligned} \omega_1 &= \omega_{AI} \\ \omega_3 &= \frac{\omega_{AII}}{i_{45}} = \frac{\omega_{AII}}{-\frac{Z_5}{Z_4}} \end{aligned}$$

Obviously, the directions of rotation of the sun gear and the ring gear must be the same, which means that the motor shafts must rotate in opposite directions, i.e.,

$$\omega_{AI} = -\omega_{AII} \quad (6)$$

The angular velocity ω_B of the output shaft B of the gearbox, resp. of the rope drum is determined by the following formula, taking into account the speed ratios of the last two stages steps

$$\omega_B = \frac{\omega_H}{i_{67} \cdot i_{89}} = \frac{\omega_H}{\frac{Z_7}{Z_6} \cdot \frac{Z_9}{Z_8}} \quad (7)$$



$$\begin{aligned} T_{AI} &= T_1 \\ T_{AII} \cdot i_{45} &= T_3 = +t \cdot T_1 \\ T_H &= -(1+t)T_1 \end{aligned}$$

Fig. 3 Reducer of hoisting mechanism of an overhead (bridge) crane with tween-motor drive with embedded planetary gear train.

3. Tween-motor driven hoisting mechanism – in failure mode working

3.1. Motor II is in failure

In this case only the motor I is working (Fig. 4), i.e.,

$$P_B = P_{AI}$$

Planetary gear train works with fixed ring gear, i.e., $\omega_1 \equiv \omega_{AI} > 0$ and $\omega_3 = 0$. The carrier angular velocity is [4]

$$\omega_H = \frac{\omega_{AI}}{i_{1H(3)}} = \frac{\omega_1}{i_{1H(3)}} = \frac{\omega_1}{1 + \frac{Z_3}{Z_1}}$$

i.e., lower than in case of work of both motors and this reflects to the output angular velocity

$$\omega_B = \frac{\omega_H}{i_{67} \cdot i_{89}} = \frac{\omega_H}{\frac{z_7 \cdot z_9}{z_6 \cdot z_8}}.$$

3.2. Motor I is in failure

In this case only the motor II is working (Fig. 5), i.e.,

$$P_B = P_{AII}$$

Planetary gear train works with fixed sun gear, i.e., $\omega_4 \equiv \omega_{AII}$

and $\omega_1 = 0$. The carrier angular velocity is [4]

$$\omega_H = \frac{\omega_{AII}}{i_{45} \cdot i_{3H(1)}} = \frac{\omega_4}{-\frac{z_5}{z_4} \left(1 + \frac{z_1}{z_3} \right)},$$

as ω_B is determined by the same formula, but with different ω_H

$$\omega_B = \frac{\omega_H}{i_{67} \cdot i_{89}} = \frac{\omega_H}{\frac{z_7 \cdot z_9}{z_6 \cdot z_8}}$$

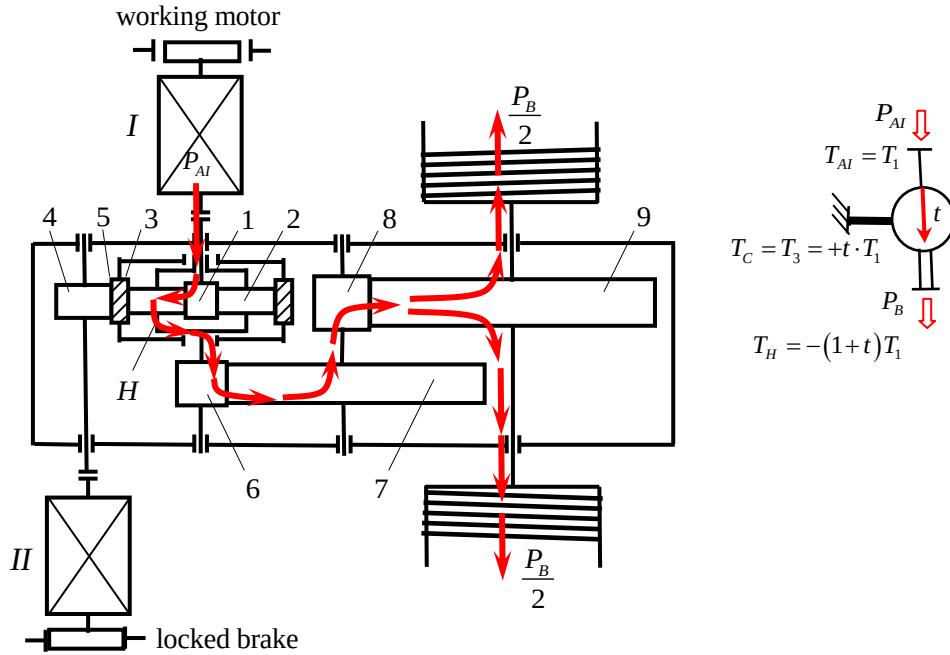


Fig. 4 The reducer from Fig. 3 with motor II off, where the planetary gear train works with fixed ring gear.

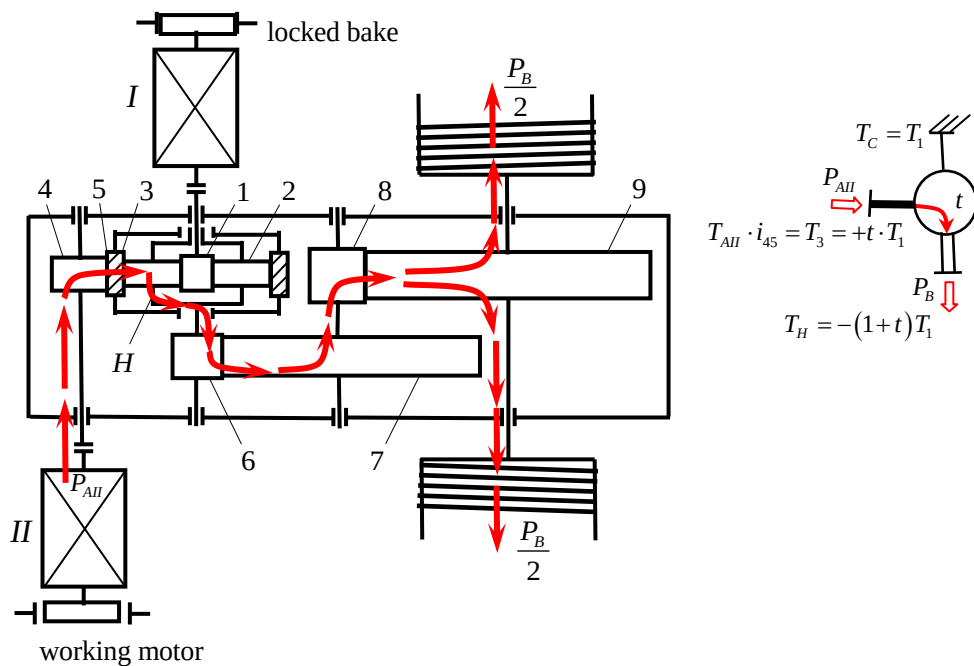


Fig. 5 The reducer from Fig. 3 with motor I off, where the planetary gear train works with fixed sun gear.

4. Kinematic analysis

Aim: Objective: to obtain the same output angular velocity ω_B . This is possible at the same angular velocity of the carrier in both cases, i.e.,

$$\omega_H = \frac{\omega_{AI}}{\left(1 + \frac{z_3}{z_1}\right)} = \frac{\omega_{AII}}{-\frac{z_5}{z_4} \left(1 + \frac{z_1}{z_3}\right)}.$$

Solution: Since the angular velocities of the motors are equal in magnitude (identical motors) and opposite in direction $\omega_{AI} = -\omega_{AII}$, following equation must be satisfied

$$\left(1 + \frac{z_3}{z_1}\right) = \frac{z_5}{z_4} \left(1 + \frac{z_1}{z_3}\right).$$

After processing, the ratio is obtained, which is obvious from the kinematic scheme (which maintains the same output torque T_H of the planetary gear train)

$$\frac{z_3}{z_1} = \frac{z_5}{z_4}.$$

5. Conclusions

In compliance with the derived dependence, both motors operate at rated power $P_{AI} = P_{AII} = 0,5 P_B$ in regular operation mode $P_{AI} + P_{AII} = P_B$ and in emergency (failure) mode. In the second case, the mechanism operates at twice less power, but at twice less angular velocity, so that the torque of the drum shaft remains the same as in regular operation.

The analysis showed that when using the more complex AI-planetary gear train, a great kinematic advantage is not achieved.

6. Acknowledgments

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Statistical analysis of marine vessel sensor data using SPM under ISO 19030

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Abstract: *Inefficient energy utilization is intolerable amongst ship operators and regulatory authorities, especially in the current era. When the condition of a ship's hull and/or propeller-s degrades, to maintain speed, there is a need for more power thus more fuel. A byproduct of the increased fuel consumption is increased Green House Gas emissions that are strictly regulated by international authorities. In the present paper Ship Performance Monitor (SPM), monitoring software used to test hypotheses about ISO 19030 application to the industry.*

1. SPM Data logging

The SPM software (Fuel and Power consumption from all major consumers on-board is accumulated, together with important inputs such as vessel speed, wind speed and direction, distance sailed, draft and trim. This data is presented in two major groups: Daily Data and Mode Data.) [7] can oversee and store enormous measure of information to make a dependable performance examination. For the performance examination, the SPM makes the performance perceptions consequently once a day, utilizing a similar arrangement of guidelines and separating. All the moment information determined each logging are separated and arrived at the midpoint of every day, giving a lot of dependable performance perceptions. Every performance perception point is put away in a database for further assessment. Moreover, all information focuses ought to be stockpiled supported up in a generally utilized arrangement for later handling. A viable answer for support up the information is to send the information all the time back to the proprietor for safe coastal capacity. The information from the sensors are not in every case enduring, to get reasonable and justifiable moment esteems for the administrators, the SPM are applying smoothing calculations to compute the normal of the information. Normally acknowledged, the logging recurrence is set to 15 s (logging time acknowledged by ISO 19030 Standard). The performance perceptions, contrasted and the gauge (structure information), will give the deviation point for those factors to be utilized in the measurable investigation. For the measurable investigation (long pattern assessment), it is built up as a solid recurrence of one performance perception for every day [2].

2. Performance reference baselines

The SPM software plots the calculated performance observations on different graphs. These graphs are showing the deviation (in percentage) for the key performance indicators. However, to make these observations more useful, a reference base is used to compare them against. Some SPM software uses two different reference levels, one constant and one dynamic [2].

3. Constant reference baselines

These reference baselines are the data from the ship's design, and they are consistent for the total lifetime of the ship, except if the hull, propeller, or primary propulsion system experiences modifications. These baselines designate the 'zero dimension' in the measurable investigation [2].

Steady reference standard for examination of speed deviation One reference level is the design data acquired from the model tank test. The data from the model tank test gives the theoretic connection between the power conveyed to the propeller and the ship's speed through the water for counterweight and design draft condition. The everyday normal of speed through the water (performance perception) looked at against this theoretic standard, gives a deviation in rate, utilized by the SPM programming. Since the speed deviation relies upon the ship's payload, the SPM will naturally insert the 'control versus speed' benchmark to any middle of the road draft esteems covering all payload potential outcomes.

Subsequently, the speed deviation esteems every day considers the vessel mean draft, ship speed through the water and the power conveyed to propeller. Fig. 2 demonstrates a case of real data acquired from model tank report.

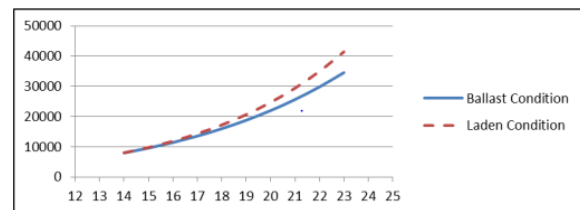


Fig. 2 : Data from model tank test for a container vessel

4. Constant reference baseline for comparison of RPM deviation

The reference curve used to calculate the deviation for the RPM is a function of the relation specified in the Propeller handbook:

$$Power = a \cdot (RPM)^{2.7}$$

$$\text{Where, } a = \frac{Power_at_MCR}{(RPM_at_MCR)^{2.7}}$$

The propeller curve contains helpful data about the working purpose of the primary motor and the propeller.

Consistent reference standard for correlation of Specific Fuel Rate (SFR) deviation This reference bend is acquired from the M/E workshop test report. The fuel type being used by the M/E impacts the computation of the SFR (g/kWh). There are a few fuel types installed with various low warming qualities (LHV) so the reference benchmark will be at one standard LHV. ISO suggests a LHV reference estimation of 42,700 kJ/kg [2].

5. Dynamic reference baselines

Another reference level is the benchmark level, made with data gathered after conveyance as well as after any significant repair/docking of the ships. At whatever point a docking is done, the administrator must set another 'pattern occasion', and the system will naturally utilize the primary months to quantify and ascertain the current 'out-of-dock' condition. This new reference level (benchmark) is made by taking the normal of various day by day perceptions (for example 60-120 performance perceptions) beginning after a noteworthy occasion. These perceptions, sifted for terrible climate and moving mode (see area 3.4 beneath), will make up the new benchmark level to think about against for the current operational period until the following pattern occasion [2].

6. Filtering applied in the SPM software

The SPM software is consequently making performance perceptions once a day. This requires setting some separating in the SPM programming to keep away from futile data to nullify the long

pattern investigation. The vessels are working in changing climate conditions, ocean flows, cruising modes (ordinary routes, moving, and so on.) and freight conditions (counterweight/loaded conditions). Because of these evolving conditions, the SPM programming must apply sifting calculations to dispose of data if there should be an occurrence of terrible climate condition (utilizing the Beaufort scale as reference) or unusual cruising mode. The performance perception is rejected for use in the factual investigation if the breeze force is over a certain Beaufort level (commonly level 6), or the primary motor burden is under 30 % MCR [3].

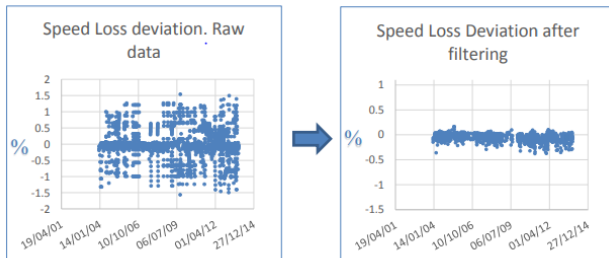


Fig. 3: Left side showing raw data, right side showing data filtered by weather and sailing mode

7. Definition of Statistical analysis applied by the SPM software

Per definition, the statistical analysis refers to the methods used to process large amounts of data and report overall trends. Statistical analysis is particularly useful when dealing with noisy data [3].

8. Statistical analysis applied

After the filtering algorithms, the software owns a new set of data, which the statistical analysis is applied. A new trend function on the form $f(x) = ax + b$ based on the filtered data points is plotted along with all the included data points as a solid line. The trend function is calculated from the data points using the linear regression model of least square fit, which is a common method in statistics to find a linear relationship between a set of data points [1].

9. Presentation of a vessel's performance

When the data is collected, filtered and analyzed, the next step is to display the vessel's performance to the onboard crew and management in the office and there are numerous different approaches for doing this, some are straight forward, others more complex [1].

10. Instant performance indication

One approach is to equip the wheelhouse with a dedicated instrument indicating if the agreed fuel consumption is exceeded or not. This can be a graphic indication of a target fuel oil consumption of 16 tons/day and be like the below example. This can work for example for bulk carriers, where the delivery timing is not so time critical, and therefore the vessel can transit in the best fuel-efficient speed [1].



Fig. 4: M/E fuel oil over-consumption and status of generators



Fig. 5: Example of instant performance dashboard⁶

11. Performance Trial Report

A welcome feature of a SPM software is to get an instant performance report of the current situation. A Performance Trial of a certain period can give the crew and management a detailed report of the vessel's performance under controlled conditions [4].

Fig. 6 shows a Performance Trial done in good weather conditions and steady state sailing:

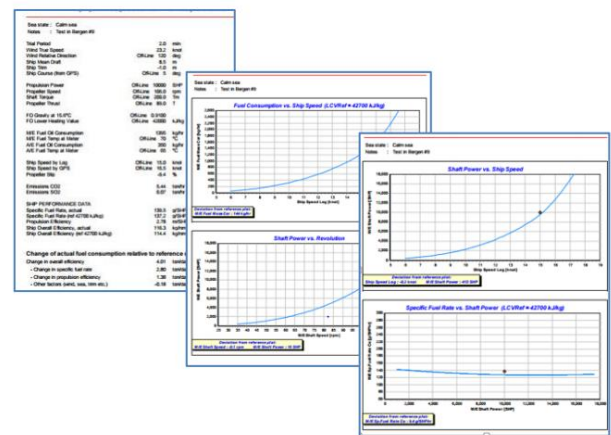


Fig. 6: Performance trial results

12. Long trend performance indication

The instant performance can be valuable but may be influenced by external factors like wind and current. However, a look at the long-term development of the vessels key performance values will statistically give you a more correct picture and with an automated data collection and filtering system in place as earlier described, a performance trend may start to evolve. This trend, shown as the percentage deviation from the design condition, will give the crew and owner a clear picture of the vessel's performance today, shown against earlier performance and design conditions. The three most important areas of interest are: - Hull condition (Shaft Power vs. Ship speed through water) - Propeller condition (Shaft Power vs.

Shaft Rpm) - M/E Specific Fuel Rate (SFR vs. Shaft Power) Is the performance gradually decreasing, how much, and what does this imply in increased fuel oil consumption? Below are some examples of long trend performance indications available for the user [5].

As Figs. 7-9 clearly indicates, after the second docking the vessel has good performance even after 4 years of sailing. Thus, saving the owner a significantly amount of fuel oil and reduced emissions compared to the first period. Using traffic light color indications, Fig. 10 shows an LNG carrier with a yearly speed loss of more than 4% (now in the red performance area) [6].

Over a period of only 2.5 years this vessel has developed a speed loss of 11.7% compared to 'out-of-dock' condition (benchmark level indicated by blue dotted line), with a theoretical increased fuel oil consumption as indicated in Fig. 11 as a result.

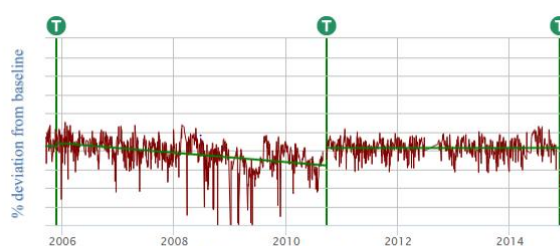


Fig. 7: Speed loss with two different anti-fouling systems.

Result		
Performance status at 22. Sep. 2010 is -11.7% compared to benchmark.		
Consequence Based on the trend data and with an assumed draft of 12 m (ρ EDIT) the following deviations from benchmark performance can be expected:		
MCR	Speed Change	Fuel Oil Impact*
40% (6240 SHP)	-1.52 knot	6.46 ton/day
50% (7800 SHP)	-1.63 knot	7.93 ton/day
75% (11700 SHP)	-1.80 knot	12.86 ton/day
90% (14040 SHP)	-1.87 knot	16.70 ton/day
* Estimated additional fuel oil required due to speed change, based on ISO corrected Caloric Value.		

Fig. 8: Large speed loss and increase in fuel oil consumption

Fig. 9: Minimum speed loss and small increase in fuel oil consumption

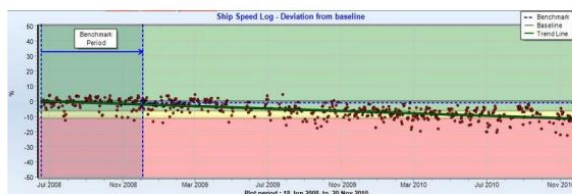


Fig. 10: Speed loss due to deteriorated hull condition

Result		
Performance status at 22. Sep. 2010 is -11.7% compared to benchmark.		
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MCR	Speed Change	Fuel Oil Impact*
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* Estimated additional fuel oil required due to speed change, based on ISO corrected Caloric Value.		

Fig. 11: Fuel oil impact of the deteriorated hull condition

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Høglund SPM All rights reserved, complies to EU MRV regulation 2015/757. Our software is certified by Verifavia as an EU MRV IT System and is compatible with Tethis MRV platform requirements. Høglund SPM is also certified as an IT system for IMO DCS reports.

Analysis reasons of wear of the locomotive wheel flange on curved sections track

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Abstract: The article deals with the problem of wear of the train wheel crest and the conditions that affect the process of deformation of the material of the wheelset parts. Factors affecting wear are considered. It is shown that the resource of ridges depends on the nature and speed of chemical and physical processes. It was noted that in the center of destruction of the ridge, an increased content of carbon, oxygen and silicon was detected. It is established that the main way to reduce wear is to lubricate the comb in order to reduce the coefficient of friction.

Keywords: RIDGE, RAIL, WEAR, LUBRICANT, DEFORMATIONS, WHEELSET.

On electric rolling stock of industrial railway transport, band wheels with disc centers are used, on the elongated hub of which a gear wheel is mounted. The wheelset of traction cars consists of an axle, cast wheel centers with bandages, fixed band rings, and solid-rolled gears. The elements of the wheelset work under different conditions and require a specific manufacturing process to ensure the necessary conditions for durability and high reliability [1]. Analysis of statistical data has shown that the main reasons for rejection of wheel sets of traction rolling stock are wear and undercutting of the ridge, as well as the occurrence of a sharp roll. As a solution to this problem, the Railways have developed a set of measures to eliminate harmful factors (coefficient of friction, hardness of the wheel and rail material, the size and shape of contact spots) and conditions (external environmental conditions – temperature, humidity, etc.) that affect the wear of the car's wheel crest and the side faces of the outer rails [2].

On curved sections of railway tracks, there are problems associated with rail wear. One of them is the wear between the wheel flange and the outer rail of the curve with no lubrication. When entering a turn arise microscopic side wheels on the rail surface (area of contact is determined by the deformation of the material at contact areas under load) which causes high impact load wheels and the end result is rapid wear of the material. These factors will affect the contact resistance and local temperatures that occur during frictional friction, and the amount of material transfer between the rubbing surfaces [3]. This effect occurs on the inner rail of a curved section. It is assumed that at the lightest loads, the micro-surfaces touch small areas and as the load increases, these areas increase in size. Some irregularities approach and touch, forming new areas of contact. This means that increasing the load increases the contact areas of the rubbing surfaces and the distribution of areas is carried out by the size of the interaction areas. Using this model, the authors derived dependencies between the applied load and the contact area [4].

$$A = B[P/C]^{2/(1+p)}$$

$$G = D[P/C]^{[(1+m)/(1+p)]}$$

where $B = \frac{1}{2}Mb$, $C = [M/(1+p)]c$, и $D = [M/(1+m)]d$; A – area of irregularities; P – load carried by the contact; C – conductivity of the contact; p – coefficient of deformation; m – coefficient of resistance to contraction.

During the sliding process, the surfaces have friction forces, between which there is an intermolecular interaction (this will include smaller contact areas). The deformation of the contact areas may appear elastic based on contact resistance measurements, and the friction between the surfaces in question will be determined by the plastic deformation of the irregularities.

The limited contact resistance measurement data is consistent with a model in which the number and average size of contact areas increase with load [5, 6].

Vorobyov A. A. and Kotova V. V. in the article [7] note that wear particles are scales or plates of different thickness. They are typical for normal wear conditions [8]. For the formation of wear particles, it is necessary that the steel reaches its ultimate deformation state, which is accelerated by the action of the surface-

active medium [9]. When wear particles are formed and detached from the metal, they adsorb the active elements of the environment inside the cracks at high speeds, and this process leads to a further process of plastic deformation of the steel. Thus, a wet environment containing various lubricants and dirt has a negative impact on the fatigue strength of the wheel surface due to adsorption and corrosion effects.

In the article [10], the author notes that the wear and life of rail ridges mainly depends on the nature and speed of chemical and physical processes that occur in the surface layers of the metal.

In [11] refers to the occurrence of friction forces between wheel and rail when the train moves, due to which work is being performed, the bulk of which goes into internal energy, leading to temperature rise of the friction surfaces, and reaches its maximum at the site of primary contact. There is also a process of adhesive wear (it depends on the roughness of the surfaces, the hardness of the material, the loading of the contact zone).

The article [12] States that wheel pair wear can occur due to mechanical interaction and the development of fatigue failure of the rubbing surfaces during abrasion, and the destruction of the material due to the engagement of surface irregularities during friction. The origin of a fatigue crack is local and occurs in places where the maximum stress is applied to the selected area. Maximum stress occurs due to non-metallic inclusions, surface irregularities, and sharp transitions between sections. In works [13.] the most dangerous areas of fatigue failure origin were identified (Fig. 1), which includes the bandage comb.



Fig. 1. Places of fatigue destruction of bandages that can serve as the beginning of fatigue wear are highlighted.

This process can be described as follows: first, under the influence of periodic shock loads that occur when the train enters the turn of the railway track, a section of a fan of microcracks is formed near the surface. Then, they grow along the planes of maximum chipping stress, both towards the surface and in the depth of the ridge. At the moment when the crack reaches its maximum size, the metal is crushed on the surface and inside the material and the material is split off from the ridge. The authors found non-metallic inclusions in the destruction center. Analysis of their chemical composition revealed an increased content of carbon, oxygen and silicon. From the results obtained, it is concluded that the destruction is due to the presence of silicates or slag formations in the structure. [14].

Previously, uncoupling of wagons was associated with contact-fatigue defects and defects in rail joints [15]. Currently, the cause of uncoupling is the side wear of the wheel crest. On average, as shown in the work, from 10,000 rails to 50,000 rails were withdrawn per year. If a train wheel fails, it will result in the failure of the entire car, while increasing the time for their repair in the railway depot. Intensive wear of the ridge is facilitated by the resulting rolls. When the train moves there is a strong interaction between the wheel material and rail material, resulting in both material displaced and contribute to the rupture of metal and the formation of mesh of cracks on the surface. In this case, the turning of the comb is required [16]. Wheel pairs are subject to turning when the rolling surface is insignificant [17]. The average intensity of wheel wear on a thin ridge is 0.5 mm per 10 thousand km of mileage (which is twice the established norm - 4 mm per 160 thousand km). The receipt of cars in the current repair is associated with 35% - 40% due to a malfunction of the wheel pairs [18]. Failures in the way are accompanied by a deterioration in the working conditions of the rolling stock – a high level of intensification of lateral wear of the wheel ridges, undercutting and rolling of the ridges. Due to the wear of the ridges, 50% of the wheels were rejected. And the wear of the ridge itself increases the power consumption for traction by 30% by 50% [19].

Kik W. and Moelle D. [20] found that a good correspondence between the experimental data and the results of wear modeling can only be achieved if a high hardness of the wheel flange is used (since the hardness affects the volume of the material during deformation). The hardness of different areas of the wheel and the coefficient of friction are specified in the simulation - the greater the hardness of the materials, the less wear on the surfaces. From the standard [21], it is known that for new wheels, the perimeter hardness is no more than 20 NV (8%).

Comparison of the available data on the wear of wheels with a hardened surface under certain conditions of the experimental circular track allowed us to estimate the coefficients of light and heavy wear, the coefficient of friction. The friction torque depends on the dimensions of center plate, center plate, the presence/absence of handling of the body, position of bearings, the friction coefficient, which depends on the tribological characteristics of the material of the contact surfaces; the value can vary from 0.25 to 0.4. The appearance of additional friction forces significantly increases the moment of resistance forces when the train enters the turn of the railway track [22]. The following values of the abrasive wear parameters were set for the wheels:

- the coefficient of friction of the wheel tread is 0.25;
- the coefficient of friction for the wheel flange is 0.28.

Thus, using different materials in the manufacture of structural parts of the wheelset system, it is possible to provide rational values of friction forces [23].

One of the ways to protect against wear is the use of alloy steel in the production of a wheelset. In the article [24], work was done to determine the degree of influence of various alloying elements on the strength characteristics of wheel steel. Steel with a carbon content (0.29% - 0.72%) was studied. The following properties of steel were determined: impact strength, contact fatigue life, wear resistance, and ductility in their normalized and hardened state. As a result of the research, it was concluded that it is impractical to use alloy steel with a carbon content of more than 0.5 %, since the positive properties of wheel steel during alloying significantly weaken with increasing carbon content. Traditional technology of steel hardening with high-frequency currents is widely used in many industries, including in the railway sector to improve the wear resistance of rolling stock wheels [25].

To reduce the wear of the car wheel crest, a lubricant is applied to the surface of the outer rail head on curved sections, which consists of a solid lubricant (consisting of graphite powder and molybdenum disulfide) and a surfactant surfactant (serpentine 5-60%, surfactant 1-20%, the remaining part is an organic binder). The organic component is the main liquid component of the lubricant, which contributes to its uniform distribution on the rails. Serpentine during the interaction of the wheel and rail acquires

anti-friction properties and forms a servovit film on the surface, which provides a continuous supply of solid-lubricating material to the friction pair. In addition, this film reduces wear on straight sections of the road. The grease supply occurs when the train turns, and when it exits the turn, the grease supply automatically stops. The disadvantage of this method is that the retention of the solid lubricant is not provided, and this leads to overspending of the lubricant [26].

One way to reduce wear is to use SKF and Lincoln lubricants. These manufacturers offer stationary track and mobile lubrication systems.

On stationary lubrication systems, a certain amount of lubricant is applied to the rail and maintains this lubricant in place. Thanks to this system, the wheels of trains completely capture the lubricant and carry it along the rails. The systems installed on the rolling stock for greasing the wheel crest are installed on the first wheel pair of the front bogie of the head car. Materials with high viscosity and friction additives are applied automatically and help to reduce wear [27, 28].

Another way to reduce the wear of the car's wheel crest is to introduce a system of lubrication of the working face of the rails using magnetically controlled contacts. When the reverse current begins to flow, the reed switch immediately turns on the pump motor, which pumps oil into the tank. Oil flows through the pipeline under pressure and lubricates the working face of the rail. The magnetically controlled contacts are sealed in a glass flask filled with nitrogen or an inert gas; they are sealed. Hence their name of reed switches – i.e. sealed contacts. In the lubrication system of the ridge is used by switching the reed switch. When a train passes through a section of track, the current flowing through the rail chain is fed to the left winding of the switching reed switch, the middle plate, closing the left contact, will give a signal to the electropneumatic contact of the oil tank. The contactor for releasing oil into the oil pipeline is activated. Under vertical load on sleepers from wheel pairs, oil with pressure will spray the rail from the side of the working face along the perimeter of the curve until the last wheel pair of the technological turntable passes. Reed switches must have a protective housing, since the contacts of the reed switch are sealed [29]. The disadvantage of this method is the instability of current flow, possible contact breaks and contact depressurization, which does not result in the treatment of the car's wheel crest with a greasable material.

Thus, the main reason for rejection of wheel pairs of traction rolling stock is wear of the ridge. To reduce the wear of the car wheel crest, a lubricant consisting of a solid lubricant and a surfactant must be applied to the rail head. The use of high-viscosity lubricants with friction additives reduces the wear of riding surfaces. To increase the wear resistance of the material, it is necessary to use steel hardened at high frequency. To reduce deformations, use a high-hard material of the wheel flange, since the greater the hardness of the material, the less deformation (wear).

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Parametric design of a waste-to-energy plant using rankine thermodynamic power cycle

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Abstract: Handling with municipal solid waste nowadays is becoming a global challenge. Albania is facing equally this issue. Although, in recent years a considerable progress has been achieved, still the country is lagging behind the EU states. In generally, the overall progress is slow and the requirements set by the policy and legal framework are not met. However, in recent years in Albania there are some developments related to solve the waste treatment dilemma. Thus, the government chose the public-private partnership model to operate in this field. Therefore currently in Albania are proposed three waste firing plants, placed in Elbasan and Tirana, central Albania and Fier, southwest of the country. The Elbasan waste to energy plant is in operation since June 2017. Another plant in Fier is projected to start operation soon. This article aims to optimize a 5.5 MW_e waste to energy plant in the Albanian conditions. Parametric design of thermodynamic properties of the WtE plant based Rankine cycle model are presented in this study. Optimization of plant efficiency in relation to extraction pressure and feed-water temperature is some of the outputs of this study.

Keywords: MUNICIPAL SOLID WASTE, ENERGY, RANKINE CYCLE, EFFICIENCY

1. Introduction

Municipal Solid Waste (MSW) management nowadays is a global challenge. In Albania this is a sharp issue as well [1]. The country has achieved a considerable progress, in the recent years, however it still cannot meet the requirements set by the policy and legal framework. The situation remains unstable due to the obstacles and shortages facing the system, such as lack of human and institutional capacities, insufficient financing, lack of implementation of plans, regulations etc. In the recent years the government took some initiatives to solve the waste treatment dilemma [2]. Thus, the public-private partnership model was chosen to operate in this field. A waste-to-energy plant placed in Elbasan, central Albania is in operation since June 2017, and two more WtE plant are going to be built soon in Tirana and Fier, 115 km distance from the capital [3].

MSW should be considered as a valuable source of energy due to their significant calorific value estimated 6-12 MJ/kg [4]. Fuel properties, such as high ash content, high moisture content 40-50% are counted as an disadvantage in respect to their thermal treatment. Municipal solid waste character as heterogeneous should be taken into consideration during thermodynamic design of such a WtE plants.

However, this method of waste treatment nowadays is successfully tested in many European countries and accepted by the public [5]. It combines the elimination of large amounts of waste with energy production, by respecting the emissions limits to atmosphere.

2. Case study

The inputs data are presented below correspond to the Fier municipality.

Table 1: Input data for the plant design

	Value	Units
Population	234,329	Inhabitants
Waste generation per year	100,000	Tonnes/year
Calorific value	10	MJ/kg
Operation period	300	Days/year

During the design and calculations some considerations have been taken into account, such as:

- Quantity of waste generated per year;
- Chemical composition and waste heterogeneity;
- Physical composition of waste (size, type, material);
- Fuel properties (heating value,, ash content, moisture content);
- Residues after combustion and specific requirements;

- Thermal capacity of the plant and energetic parameters;
- Emissions limits requirements;
- No cost consideration for this case.

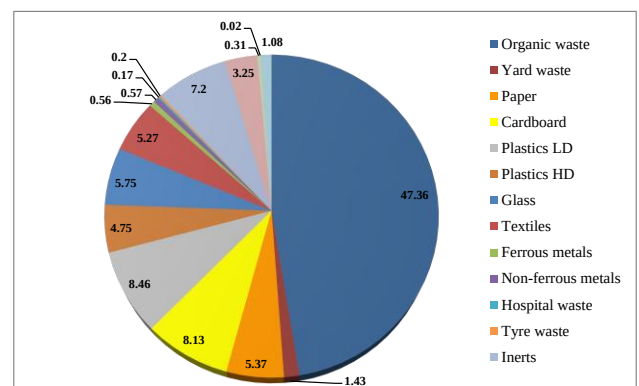


Fig. 1 Composition of Municipal Solid Waste in % [6].

Combustion of MSW will take place in moving grate boilers, which represent the main technology nowadays for handling with thermal treatment of waste. Approximately 125 plants around Europe operate on this technology basis. Thermal processing of waste takes place in this part of the plant and the entire process lasts from 40 – 60 minutes until the ash and slags being removed.

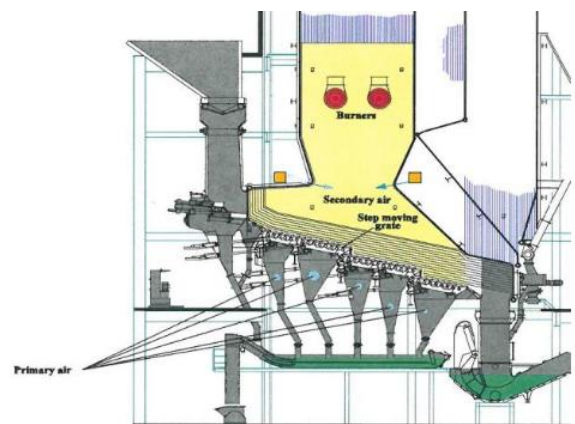


Fig. 2 Moving grate technology for waste to energy application [7].

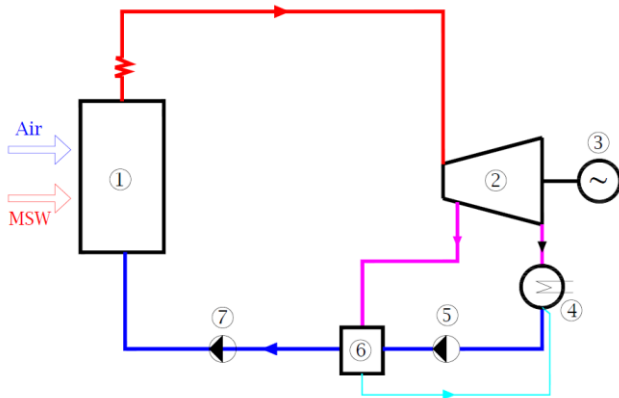
For the energy analysis of the plant characteristics it is necessary setting the steam parameters of the boiler. Overall accepted steam parameters for this technology currently in

operation estimate $p=40$ bar and $T=400^{\circ}\text{C}$. This is strictly conditioned by the corrosive properties of waste. In table 2 are shown the main parameters of the power plant.

Table2: Waste to energy plant characteristic parameters

Description	Value	Unit
MSW capacity	12.5	t/h
Boiler thermal capacity	28.42	MW_{th}
Boiler efficiency	82	%
Admission pressure	40	bar
Admission temperature	400	$^{\circ}\text{C}$
Electric Plant power	5.5	MW_e
Electricity generation	36,000	MWh/year
Ash residues	10-15	%

In this study we are focused on the vapor Rankine cycle fuelled by MSW. Energy analysis consists on estimation of thermodynamic properties of each parameter of the Rankine cycle. Thus, thermal capacity of the boiler and steam generation has been evaluated as presented in Table 2.



Legend: 1-Steam boiler; 2- Steam turbine; 3- Generator
4-Condenser; 5-Circulation pump; 6-Regenerator
7-High pressure pump

Fig.3. Diagram of Rankine thermodynamic cycle

Thermal capacity of the boiler is estimated based on equation (1)

$$Q_{\text{Boiler}} = \frac{M_{\text{NU}}}{3600} \cdot H_U \cdot \eta_{\text{Boi}} = \frac{12500}{3600} \cdot 10 \cdot 0.82 = 28.47 \text{ MW}_{\text{the}} \quad (1)$$

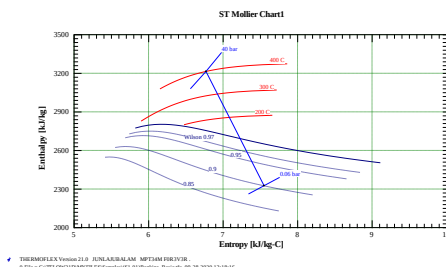


Fig. 4 Enthalpy difference for steam expansion in turbine in h-s diagram

Whereas the steam production capacity is given on equation (2)

$$\dot{m}_{\text{steam}} = \frac{Q_{\text{Boiler}}}{\Delta h} = \frac{Q_{\text{Boiler}}}{3211 - 440.2} = \frac{28470}{3211 - 440.2} = 10.01 \text{ kg/s}; \quad (2)$$

Enthalpy change in steam turbine is shown in Fig.4, and the enthalpy values are extracted from steam diagrams. The turbine isentropic efficiency is calculated by the following formula:

$$\eta_t = \frac{h_{\text{in}} - h_{\text{out}}}{h_{\text{in}} - h_{\text{theoretical}}} \quad (3)$$

From the calculations turbine isentropic efficiency results 77%. The work realized by turbine depends by inlet and outlet steam enthalpy properties. Steam turbine energy output is calculated by the simple following formula:

$$P_{\text{turbine}} = \frac{\dot{m}_{\text{steam}}}{3.6} \cdot \Delta h \quad (4)$$

And power output of the plant is given by:

$$P_{\text{el}} = P_{\text{turbine}} \cdot \eta_{\text{mech}} \cdot \eta_{\text{gen}} = 5.514 \text{ MW}_{\text{el}}$$

Plant energy demand for its operation estimated at 1200kW.

3. Optimization results

After defining the main parameters of the plant by the above assumptions we could optimize the following parameters of the plant. Indeed for this study pressure extraction and feed-water temperature are simulated to give the optimal values. The results of the simulations are shown in details in Fig.5 and Fig.6.

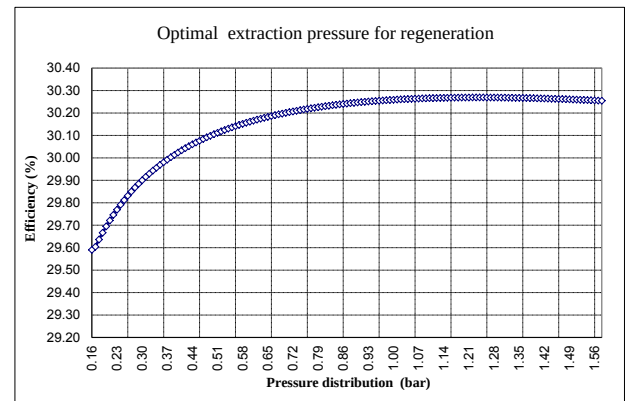


Fig.5 Plant efficiency to extraction pressure

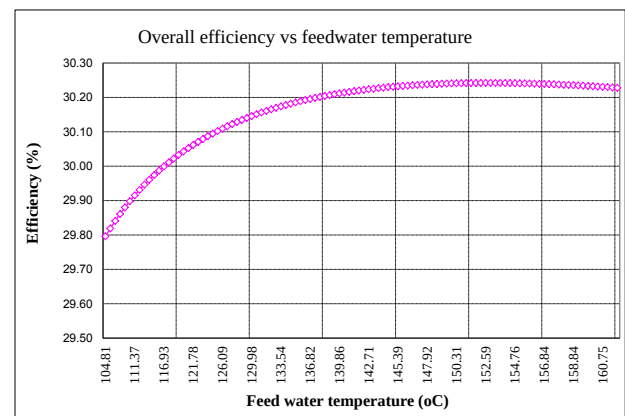


Fig.6 Efficiency profile to feedwater temperature

The maximum plant efficiency reached at $p=1.1$ bar extraction pressure from the turbine. Whereas feed water temperature profile to plant efficiency indicates $t=147.9^{\circ}\text{C}$ as optimum temperature for boiler feed-water. Analogically we can proceed to different optimum parameters of the plant, however for this study we are limited only on these two indicators.

4. Conclusions

The concept of MSW to energy was analysed in this work. The case of Albania has been considered. In the recent years this technology is proposed as a long-term solution for waste problematic. However, MSW represent a valuable source of energy regardless of their heterogeneous character, rich in moisture, and still facing the public concern on waste burning. This study aims optimization of a thermodynamic cycle running by waste combustion. Therefore, after setting the input data to the model the results obtained from calculation estimate 5.5MW electricity. A series of calculation are carried out in order to obtain optimum extraction pressure of turbine which is 1.1 bar and optimum feedwater temperate. Feedwater temperature value results at 147.9°C. It is interesting to control the pressure and temperature profile, in order to efficiently operate the power plant. As can be viewed by the graph they have direct influence on plant efficiency. Other parameters with high importance such as flue gas temperature, flue gas composition and ash content after burning should be subject for another study in this field.

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The wind gusts effects on human body based on cfd simulations

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Abstract: In this paper, the impact of wind forces on human bodies is shown. Like many meteorological phenomena, the influence of wind energy applied to human bodies is inevitable which comes into the spotlight of the scientist only when the wind becomes violent and extremely disturbing. Based on weather and observations in February 2019, abnormal wind characteristics in Albania are evidenced. On February 23, 2019, a very special situation in the Northern part of Albania, the region of Puka, with extreme values of wind parameters causing the phenomenon of "wind gust", leading to a series of material damage and loss of human life, is evidenced. Researchers and predictors need scientific information on the impact of strong winds applied on the human body for specific conditions. Wind speed values in this region of the northern part of our country set records reaching extremely values ($30 \div 35$) ms^{-1} on the ground level. Taking a cue from this unprecedented situation, the effect of strong winds on the determination of aerodynamic forces acting on the human body using numerical simulations has been studied and so far, well investigated. For this study, we considered a human body with a height of 172cm. The investigation takes into account two different positions against the wind, frontal and lateral position traversed by wind speeds levels of 20m/s, 30m/s, and 40 m/s. The study concluded that strong winds can exhibit unimaginable and unaffordable forces, leading to fatal consequences for human life.

Keywords: CFD, Forensic Science, OpenFOAM, Wind Drag, Wind Gust.

1. Introduction

On 23rd February 2019, the wind speed during that day was at moderate conditions reaching values of 11 m/s where at some point values up to 30 m/s is identified, so there was a sudden increase in speed [1]. Referring to an online site for the forecast and history of climate change of the weather, www.ventusky.com, it turns out that on February 23, 2019, at 14:00 (an approximate hour with the occurrence of several accidents causing loss of human life) wind gust with values as it is shown in the figure1 is observed:

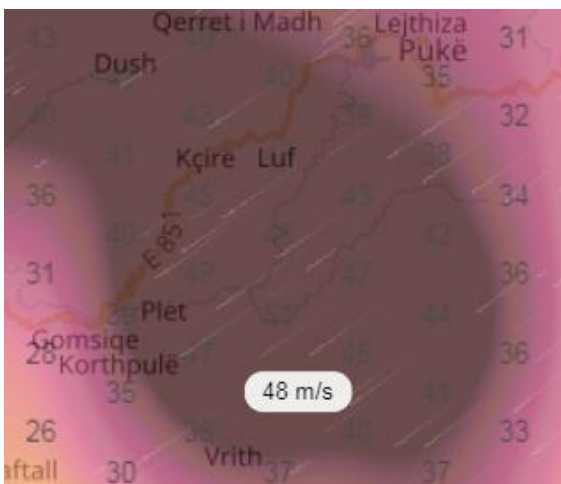


Fig. 1 Wind gusts speed in the region of Puka [2]

In the area where the accidents occurred, there were strong winds in the range of $20 \div 40$ m/s. In this case study, the velocities of the wind gust of 20m/s, 30m/s, 40m/s are assumed.

Referring to the documents in the event under investigation, it turns out that at the scene there was an ice hearth, which can be eliminated by simply throwing a quantity of salt in it, excluding the need for snow-clearing machinery.

Referring to the mechanism of the event, the worker, tends to get into the truck by placing his left foot on the rear tire of the vehicle and holding with his left hand the body of the vehicle, a position which is not very stable and as a result of wind force the worker loses his balance. The expert group asked to judge the impact of strong winds on the worker's body.

The phenomena of a sudden increase in wind speed, the duration of which is less than 20 seconds, are known as the "Wind Gust". This is a sudden and unidentifiable phenomenon and work process must be immediately interrupted.

2. The impact of wind in general

If the wind blows towards an object, it loses speed due to the obstacle that the object exhibits to the wind and according to Newton's second and third laws, equal opposites forces are exerted between the wind and the object. These forces, functions of wind speed are caused by two components [3]:

- Frictional forces usually occur between the wind and a stationary object, in contact with the body the wind speed is reduced to zero by the coefficient of friction of the object. This force component depends on the geometry, the roughness of the object surface and the nature of the flow.
- Pressure forces are generated and are a function of the shape and size of the object. Generally, bodies with large transverse surfaces generate a larger pressure force due to the Bernoulli effect.

Resistance forces consist of two components, the friction force component and the pressure force component. Both of these forces have their components in the direction of fluid flow motion. The coefficient of resistance is determined as follows [3], [4]:

$$C_D = C_{D \text{ Friction}} + C_{D \text{ Pressure}}$$

The components of the pressure and friction force perpendicular to flow's direction tend to move the body towards and the sum of these forces gives what is called the resistance force. The wind resistance force can be expressed by the following equation [5], [6]:

$$F_D = \frac{1}{2} \cdot \rho \cdot C_D \cdot S \cdot V^2$$

$\rho = 1.275 \text{ kg/m}^3$, calculated air density, referring to pressure 1.015 bar and temperature 5°C

C_D , the coefficient of resistance of the body
 S , the surface of the cross-section of the body,
 V , the wind speed

The power of this wind resistance force is given by equation [3]

$$P_D = F_D \cdot V = \frac{1}{2} \cdot \rho \cdot C_D \cdot S \cdot V^3$$

The same equations are used for the lifting force, given the lifting force coefficient:

$$P_L = F_L \cdot V = \frac{1}{2} \cdot \rho \cdot C_L \cdot S \cdot V^3$$

$$F_L = \frac{1}{2} \cdot \rho \cdot C_L \cdot S \cdot V^2$$

C_D, C_L , coefficients that are determined experimentally or in our study through numerical simulations.

To determine the strength of wind resistance on a body, the front surface on which the wind will strike must first be determined [7].

The values of the body's surface area as a function of the position and mode of action of wind force on the human body are

given. In this case study, a human body with a height of 172cm (same length as the worker who loses his life) is considered.

Referring to the sketch of the scene, two positions of the worker's body as a function of wind direction is assumed. The first case, the frontal position, parallel to the direction of wind flow and the second is intended to be perpendicular to the direction of wind movement, lateral position.

The total body surface area of a person with a height of 172cm is 1,892 m². If the position of the human body against the wind is frontal, the frontal surface area is 0.555 m². If the position of the human body against the wind is lateral, its lateral surface area is reduced to 0.325 m².



Fig.2 The body position of the person and the projected surface area

3. Numerical analysis

To understand the impact that wind has on various objects, thus experiments employing wind tunnels is required. In our country, such tunnels are not available. In recent years computer programs have managed to study various phenomena of fluid flow in virtual environments, performing numerical simulations. The expert group owns a computational fluid dynamics software, OpenFOAM version 3.0.x [8], in which the effect that the wind exhibits on the human body can be verified. For this act of expertise, a virtual wind tunnel with length and width of 5x5m and 20m long is assumed.

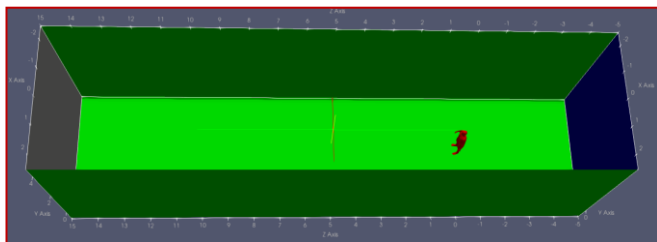


Fig. 3 Virtual wind tunnel overview

In the center of this tunnel, a body with a height of 172cm, the same height as the worker, is placed. To get as close as possible to the circumstances of the event, the person's body was raised 0.8m from the ground, a deliberate position above the tire of the vehicle, in an attempt to catch the shovel and then throw salt on the ice hearth. In this way, the impact that wind has on a person's body by setting wind speed values is calculated. From the CFD simulation, the values of pressure forces and the level of drag and list forces acting on the body of the person are evaluated.

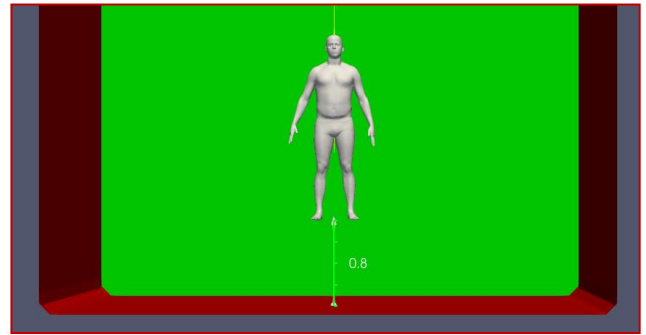


Fig. 4 The position of the person's body¹ to the wind tunnel

4. CFD simulation results

4.1 Technical analysis No.1 - wind gust speed of 20m/s

a) Frontal position in parallel wind flow direction

From the numerical simulations, for a wind speed 20m/s, the following results for the frontal position: $F_D = 126.956$ N and $F_L = 2.818$ N are carried out.

By using these data the coefficient of drag force and the coefficient of lift force is determined, respectively:

$$C_D = \frac{2 \cdot F_D}{\rho \cdot C_D \cdot S \cdot V^2} = \frac{2 \cdot 126.956}{1.275 \cdot 0.555 \cdot 20^2} = 0.90$$

$$C_L = \frac{2 \cdot F_L}{\rho \cdot C_D \cdot S \cdot V^2} = \frac{2 \cdot 2.818}{1.275 \cdot 0.555 \cdot 20^2} = 0.02$$

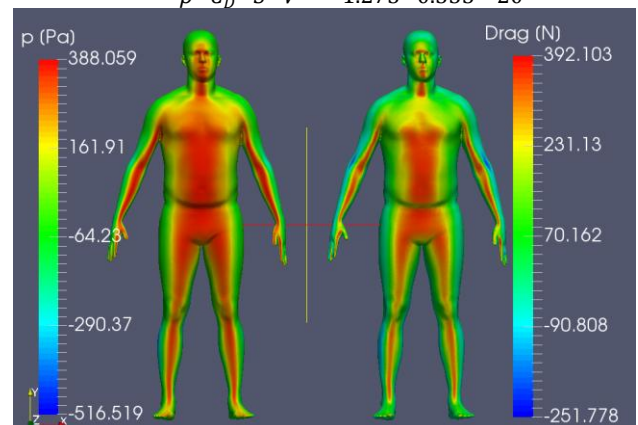


Fig. 5 The pressure field and the Drag forces on the human body (frontal position)

b) Lateral position with the direction of wind movement.

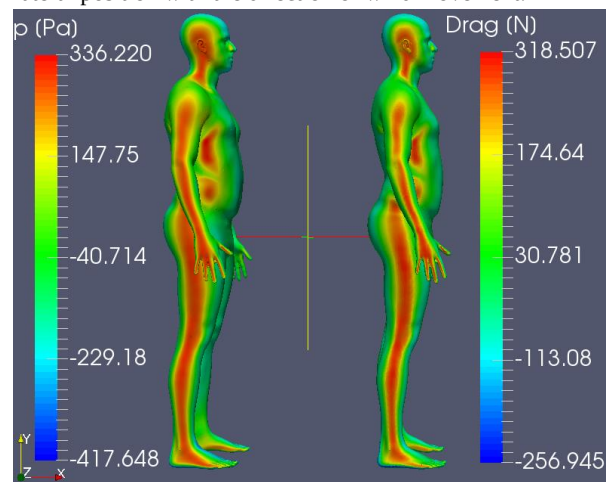


Fig. 6 The pressure field and the Drag forces on the human body (lateral position)

¹ <https://free3d.com/3d-models/human>

From the numerical simulations, for the assumed wind speed of 20m/s, by surface integration the following results are obtained:

$$F_D = 69.4322 \text{ N and } F_L = 5.35977 \text{ N}$$

Employing the above data the coefficient of resistance force and the coefficient of lifting force, is determined respectively:

$$C_D = \frac{2 \cdot F_D}{\rho \cdot C_D \cdot S \cdot V^2} = \frac{2 \cdot 69.4322}{1.275 \cdot 0.325 \cdot 20^2} = 0.840$$

$$C_L = \frac{2 \cdot F_L}{\rho \cdot C_D \cdot S \cdot V^2} = \frac{2 \cdot 5.35977}{1.275 \cdot 0.325 \cdot 20^2} = 0.065$$

Since the lifting force is very small compared to the strength of drag force resistance, it is excluded in the calculation.

4.2 Technical analysis No.2 - wind gust speed of 30m/s

a) Frontal position with the direction of wind movement.

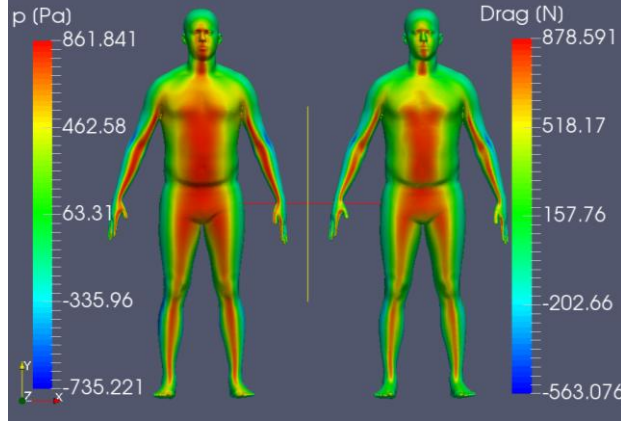


Fig. 7 The pressure field and the Drag forces on the human body (frontal position)

From the numerical simulations, for the assumed case of wind speed of the order of 30m/s, the following results are calculated:

$$F_D = 272.009 \text{ N}$$

$$C_D = \frac{2 \cdot F_D}{\rho \cdot C_D \cdot S \cdot V^2} = \frac{2 \cdot 272.009}{1.275 \cdot 0.555 \cdot 30^2} = 0.857$$

b) Lateral position with the direction of wind movement.

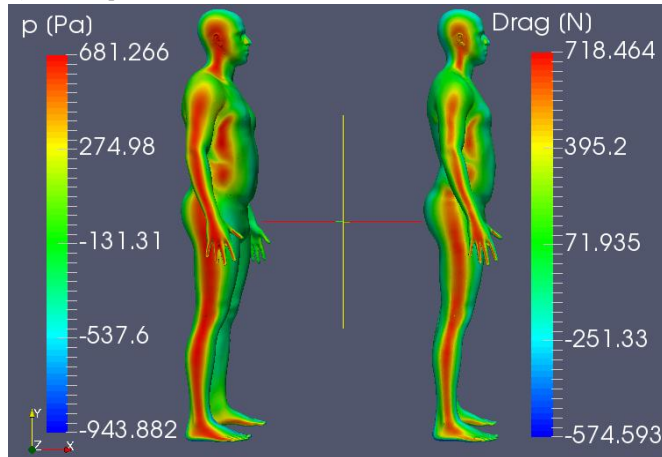


Fig. 8 The pressure field and the Drag forces on the human body (lateral position)

From the numerical simulations, for the assumed wind speed of 30m/s, the following results are obtained:

$$F_D = 155.612 \text{ N}$$

$$C_D = \frac{2 \cdot F_D}{\rho \cdot C_D \cdot S \cdot V^2} = \frac{2 \cdot 155.612}{1.275 \cdot 0.325 \cdot 30^2} = 0.837$$

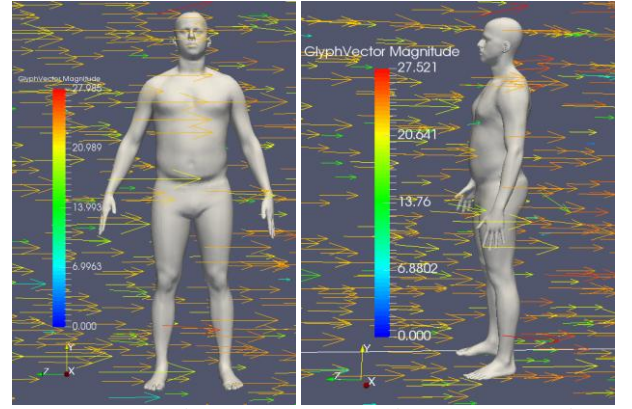


Fig.9 The velocity field on the human body for the wind speed of 30m/s (frontal and lateral position)

4.3 Technical analysis No.3 - wind gust speed of 40m/s

a) Frontal position with the direction of wind movement.

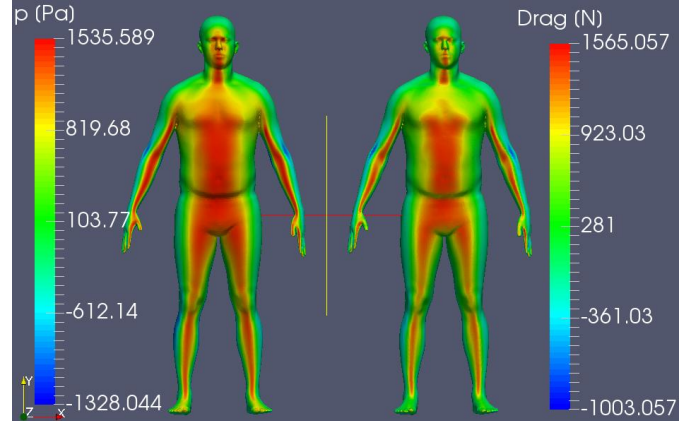


Fig. 10 The pressure field and the Drag forces on the human body (frontal position)

From the numerical simulations, for the assumed case of wind speed 40m/s, the following results are calculated:

$$F_D = 479.672 \text{ N}$$

$$C_D = \frac{2 \cdot F_D}{\rho \cdot C_D \cdot S \cdot V^2} = \frac{2 \cdot 479.672}{1.275 \cdot 0.555 \cdot 40^2} = 0.85$$

b) Lateral position with the direction of wind movement.

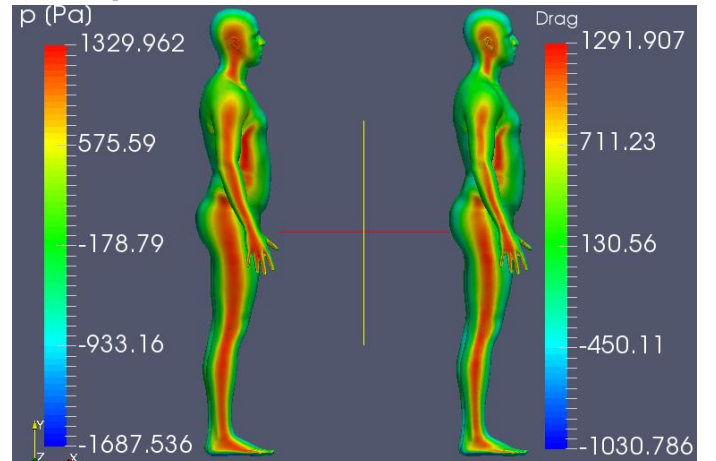


Fig. 11 The pressure field and the Drag forces on the human body (lateral position)

From the numerical simulations, for the assumed case of wind speed 40m/s, the following results are obtained:

$$F_D = 277.65 \text{ N}$$

$$C_D = \frac{2 \cdot F_D}{\rho \cdot C_D \cdot S \cdot V^2} = \frac{2 \cdot 277.65}{1.275 \cdot 0.325 \cdot 40^2} = 0.84$$

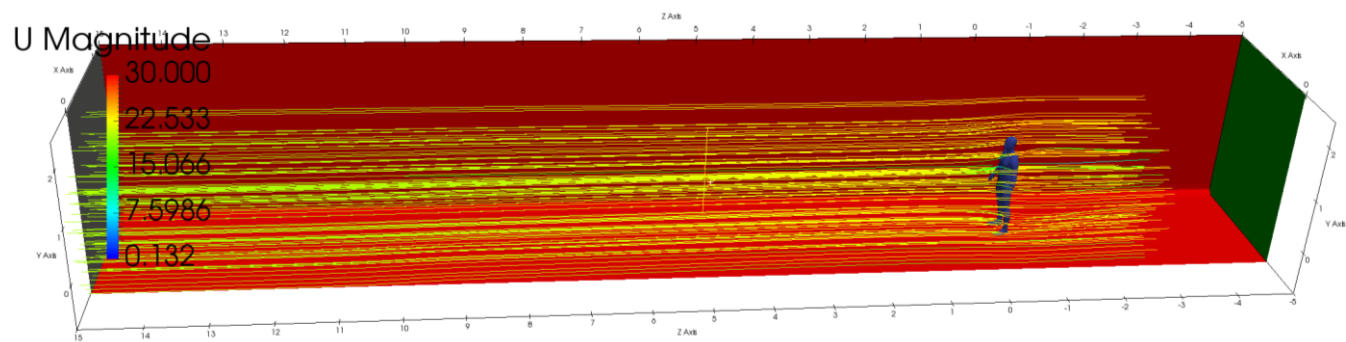


Fig. 12 Wind streamlines in the wind tunnel for the wind speed velocity 30m/s

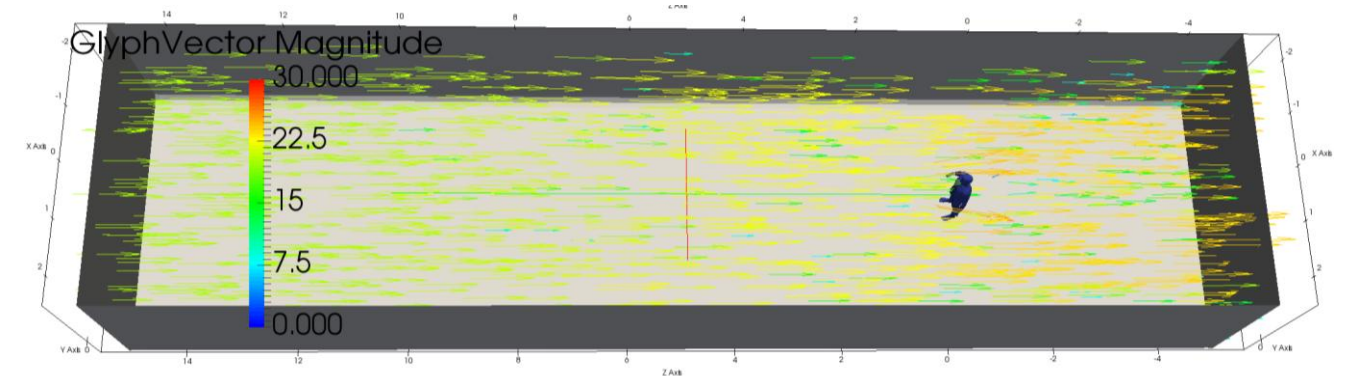


Fig. 13 Wind glyph vector magnitude in the wind tunnel for the wind speed velocity 30m/s

4. Comparison of the obtained results

The results from the numerical simulations should be verified at best by conducting experiments, which is not possible in our conditions, so the simulation results performed in this case study will be accepted as realistic values and validated to that of the analytical methods known for wind impact as well the results of experiments obtained from other studies [10], [11].

Table 1. Summary results from numerical simulations

The position of the human body against the wind	Wind speed [m/s]	Drag Force [N]	C _D [-]
Frontal position	20	126.956	0.9
	30	272.009	0.857
	40	479.672	0.85
Lateral position	20	69.432	0.84
	30	155.612	0.837
	40	277.650	0.84

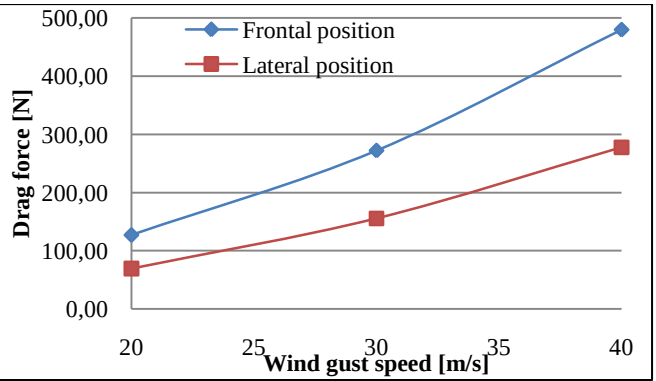


Fig. 12 Drag force on human body function of wind speed

According to (M. Kemal Atesmen) [9] are defined the minimum and maximum values of the drag forces by the wind on the human body referring to the frontal position. Values are given as a function of human body height in cm. In our case study, the worker has a height of 172cm.

Table 2. Wind speed scales [9]

V _{wind}	Min (km h ⁻¹)	Max (km h ⁻¹)	Min (m s ⁻¹)	Max (m s ⁻¹)	Min (mph)	Max (mph)
Storm	88.4	101.4	24.6	28.2	55	63
Violent storm	103.3	117.5	28.6	32.6	64	73
Hurricane cat 1	119.1	152.9	33.1	42.5	74	95
Hurricane cat 2	154.5	177.0	42.9	49.2	96	110
Hurricane cat 3	178.6	207.6	49.6	57.7	111	129
Hurricane cat 4	209.2	251.1	58.1	69.7	130	156
Hurricane cat 5	252.7	Above	70.2	Above	157	Above

The following graph in figure 13 shows the level of drag force exerted by the wind in storm conditions, for wind speed levels of 24.6 ÷ 28.6m/s. This is referring to a normal body weight, with a BMI of 22, of 65kg.

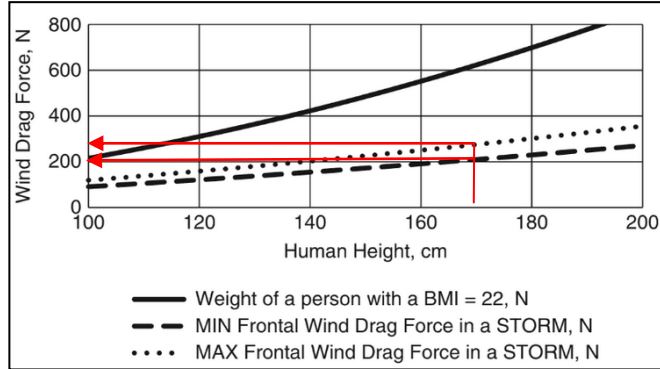


Fig.13 Frontal wind drag force on a human body versus human height in a storm [9]

The graph above shows that the values of wind forces are in the range 200÷280 N (for wind speed 24.6 ÷ 28.2m/s), for the body height of 172cm. Such values are comparable to the results obtained from numerical simulations (simulations are performed for wind speeds in the range of 20 and 30m/s).

5. Conclusion

From the numerical simulations, for the assumed wind speed of 20m/s, 30m/s and 40m/s, the following results for the frontal position are obtained:

The level of pressure on the human body can reach up to 1535 Pa and the drag force from the wind can reach the value respectively:

$$F_{D_{20m/s}} = 126.956 \text{ N}$$

$$F_{D_{30m/s}} = 272.009 \text{ N}$$

$$F_{D_{40m/s}} = 479.672 \text{ N}$$

From the numerical simulations, for the assumed wind speed of 20m/s, 30m/s and 40m/s, the following results for the lateral position are obtained:

The level of pressure on the body of the person can reach up to 1330 Pa and the drag force from the wind can reach the value respectively:

$$F_{D_{20m/s}} = 69.432 \text{ N}$$

$$F_{D_{30m/s}} = 155.612 \text{ N}$$

$$F_{D_{40m/s}} = 277.650 \text{ N}$$

From the results of numerical simulations performed in very scientific program, OpenFOAM version 3.0.x, there are observed the lifting forces, as a consequence of the influence of the wind, but these forces are incomparable to the strength of the drag forces and for this purpose have not been considered.

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Energy and exergy evaluation of CO₂ closed-cycle gas turbine

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Abstract: This paper present energy and exergy evaluation of CO₂ closed-cycle gas turbine process. The most important operating parameters of the whole observed cycle, as well as of each of its constituent components are presented and discussed. In the observed process, produced useful mechanical power for the power consumer drive is equal to 5189.78 kW, while the energy efficiency of the whole cycle is equal to 36.6%. Heat Regenerator is a crucial component of the observed process – without its operation energy efficiency of the whole cycle will be equal to only 16.91%. From the exergy aspect, Turbocompressor (TC) and Turbine (TU) shows good performances because its exergy efficiencies are higher than 90%. Regenerator exergy efficiency could be increased by lowering the temperature of the ambient in which analyzed CO₂ closed-cycle gas turbine operates.

KEYWORDS: CLOSED-CYCLE GAS TURBINE, CO₂, ENERGY ANALYSIS, EXERGY ANALYSIS

1. Introduction

Gas turbines are nowadays widely used in a power production as a stand-alone devices [1], as a part of a complex combined-cycle power plants [2], in cogeneration systems [3], etc. Gas turbines also found its implementation in marine power and propulsion systems as a primary propulsion element [4], part of a complex ship energy system [5] or as an auxiliary element in additional power production [6].

In the literature can be found many researches of gas turbines with various upgrades [7, 8] or without any upgrade [9]. However, the majority of researches are related to open-cycle gas turbines and its performances, closed-cycle gas turbines are exploited in the literature much lower.

Closed-cycle gas turbines offers various benefits in comparison to open-cycle gas turbines. They can use various operating mediums, which are non-corrosive, which offers better thermodynamic characteristics (when compared with air and combustion gases) and they did not have any connection with the environment. Also, produced useful power in such processes can be easily regulated by changing of operating medium mass flow rate.

Disadvantages of closed-cycle gas turbines can be found in a fact that used operating mediums are usually expensive and cannot be always found in the market, such cycle requires additional plant for operating medium storage, heaters and coolers inside the process have huge dimensions, etc.

In this paper is analyzed closed-cycle gas turbine which operating medium is CO₂. It is investigated operation performances, transferred heat through the process as well as efficiencies and losses (destructions) from the energy and exergy aspect. Heat Regenerator is an essential component of this closed-cycle gas turbine, so it is also presented a change in its exergy efficiency and exergy destruction during the ambient temperature change.

2. Description and operating characteristics of the analyzed CO₂ closed-cycle gas turbine

Scheme of the analyzed CO₂ closed-cycle gas turbine along with operating points required for the analysis is presented in Fig. 1. Turbocompressor (TC) increases CO₂ pressure and delivers it to Heater (through the Regenerator). In the Heater occurs main CO₂ heating and after Heater CO₂ with the highest temperature in the process is delivered to Turbine (TU). For the heating purposes in the Heater can be used any fuel or any heat type (as for an example, it can be used waste heat from some other processes). After Heater, CO₂ expands inside the Turbine and after the Turbine is delivered to Regenerator.

The Regenerator is a vital part of the whole process – without it, the efficiency of this process will be unacceptable low (shown later in the analysis) [10]. In the Regenerator CO₂ with the higher temperature (after Turbine) is used for heating of CO₂ after Turbocompressor (which has lower temperature). Therefore, Regenerator decreases the amount of heat transferred to CO₂ in the Heater. After heat transfer in the Regenerator, CO₂ is delivered to Cooler which decreases its temperature to the Turbocompressor inlet temperature. For the cooling purposes can also be used any

type of cooling medium. After Cooler, the whole process is continuously repeated. As can be seen already from the presented scheme, the whole process did not have any connection with the environment. However, the ambient parameters (dominantly the ambient temperature) can significantly influence exergy efficiencies and exergy destructions of all the components from the observed process.

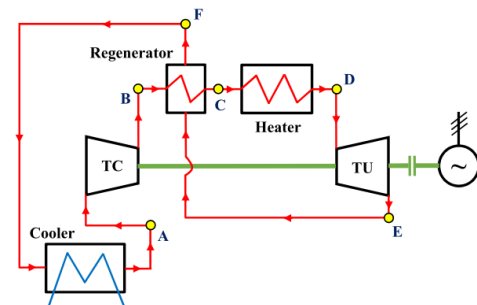


Fig. 1. Scheme of the analyzed CO₂ closed-cycle gas turbine along with operating points required for the analysis

General overview of the analyzed CO₂ closed-cycle gas turbine process (*T-s* diagram) is presented in Fig. 2. It should be noted that for the observed process pressure drops in Regenerator, Heater and Cooler (process losses) are neglected, but they are usually lower in comparison with the same components from open-cycle gas turbines [11]. Therefore, the whole process operates between two constant pressures (p_A and p_B). For the Turbocompressor, ideal (isentropic) compression is marked with operating points A-Bis, while real (polytropic) compression is marked with operating points A-B. Identical principle is used for the Turbine where ideal (isentropic) expansion is marked with operating points D-Eis, while real (polytropic) expansion is marked with operating points D-E, Fig. 2.

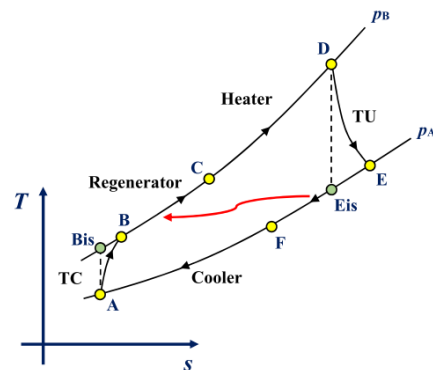


Fig. 2. *T-s* diagram of the analyzed CO₂ closed-cycle gas turbine (general overview) along with operating points required for the analysis (in accordance with Fig. 1)

3. Equations for the energy and exergy evaluation of the observed system

3.1. Overall energy and exergy equations

Energy analysis of any system or a control volume is related to the first law of thermodynamics [12-14]. The general energy balance equation valid for any system or a control volume (while disregarding potential and kinetic energies) [15, 16] can be defined as:

$$\dot{Q}_{IN} + P_{IN} + \sum \dot{E}n_{IN} = \dot{Q}_{OUT} + P_{OUT} + \sum \dot{E}n_{OUT}, \quad (1)$$

where P in (kW) is used or produced mechanical power and $\dot{Q}$ in (kW) is energy heat transfer. Index IN is related to the inlet (input), while index OUT is related to the outlet (output). $\dot{E}n$ in (kW) is a total energy of operating medium flow [17] which is defined as:

$$\dot{E}n = \dot{m} \cdot h, \quad (2)$$

where $\dot{m}$ in (kg/s) is operating medium mass flow rate and h in (kJ/kg) is operating medium specific enthalpy.

Exergy analysis of any system or a control volume is related to the second law of thermodynamics [18]. The general exergy balance equation valid for any system or a control volume is defined according to [19] as:

$$\dot{X}_{heat} + P_{IN} + \sum \dot{E}x_{IN} = P_{OUT} + \sum \dot{E}x_{OUT} + \dot{E}x_D, \quad (3)$$

where $\dot{E}x_D$ is exergy destruction in (kW) and $\dot{X}_{heat}$ in (kW) is the exergy transfer by heat at the temperature T , which can be defined by an equation [20]:

$$\dot{X}_{heat} = \sum (1 - \frac{T_0}{T}) \cdot \dot{Q}. \quad (4)$$

In Eq. 4, T is a temperature in (K), and index 0 is related to the state of the ambient in which system or a control volume operates. A total exergy of operating medium flow $\dot{E}x$ in (kW) can be calculated according to [21]:

$$\dot{E}x = \dot{m} \cdot \varepsilon, \quad (5)$$

where ε is specific exergy of operating medium in (kJ/kg) [22, 23].

3.2. Equations and principles for the energy and exergy evaluation of the analyzed CO₂ closed-cycle gas turbine

Equations and principles for the energy and exergy evaluation of the observed CO₂ closed-cycle gas turbine are based on operating points presented in Fig. 1 and Fig. 2.

Energy analysis equations

Equations for ideal and real mechanical power of Turbocompressor (used mechanical power), Turbine (produced mechanical power) and Useful power (the difference between produced and used mechanical power) as well as transferred heat to CO₂ (in Regenerator and Heater) and transferred heat from CO₂ to cooling medium in Cooler are presented in Table 1.

Table 1. Power and transferred heat for the observed process

Component	Real (polytropic) mechanical power	Eq.	Ideal (isentropic) mechanical power	Eq.
Turbocompressor (TC)	$P_{TC,RE} = \dot{m}_{CO_2} \cdot (h_B - h_A)$	(6)	$P_{TC,ID} = \dot{m}_{CO_2} \cdot (h_{Bis} - h_A)$	(9)
Turbine (TU)	$P_{TU,RE} = \dot{m}_{CO_2} \cdot (h_D - h_E)$	(7)	$P_{TU,ID} = \dot{m}_{CO_2} \cdot (h_D - h_{Eis})$	(10)
Useful	$P_{Useful,RE} = P_{TU,RE} - P_{TC,RE}$	(8)	$P_{Useful,ID} = P_{TU,ID} - P_{TC,ID}$	(11)
Component	Transferred heat		Eq.	
Regenerator	$\dot{Q}_{Regenerator} = \dot{m}_{CO_2} \cdot (h_C - h_B)$		(12)	
Heater	$\dot{Q}_{Heater} = \dot{m}_{CO_2} \cdot (h_D - h_C)$		(13)	
Cooler	$\dot{Q}_{Cooler} = \dot{m}_{CO_2} \cdot (h_F - h_A)$		(14)	

The energy efficiency of the whole observed cycle (with the Regenerator) is:

$$\eta_{n,cycle,Reg} = \frac{P_{TU,RE} - P_{TC,RE}}{\dot{m}_{CO_2} \cdot (h_D - h_C)}. \quad (15)$$

The importance of Regenerator operation in the observed closed-cycle can be seen on the best possible way if the energy efficiency of the observed process (Eq. 15) is compared with the energy efficiency of the same process, but without Regenerator (in such process CO₂ after Turbocompressor will be delivered directly to Heater and after the expansion in the Turbine CO₂ will be delivered directly to Cooler). It should be noted that Regenerator operation influences heat transfer in the Heater and Cooler, it did not have any influence on the Turbocompressor and Turbine operation. The energy efficiency of the whole observed cycle (without the Regenerator) is:

$$\eta_{n,cycle,Without Reg} = \frac{P_{TU,RE} - P_{TC,RE}}{\dot{m}_{CO_2} \cdot (h_D - h_B)}. \quad (16)$$

Exergy analysis equations

Due to insufficient data of heating medium in Heater and of cooling medium in Cooler, exergy analysis is performed for three components of the observed process – Turbocompressor, Turbine and Regenerator. In Table 2 are presented final exergy analysis equations which define exergy destructions (exergy losses) and exergy efficiencies of each observed component.

Table 2. Exergy analysis equations for the Turbocompressor, Turbine and Regenerator

Component	Exergy destruction	Eq.
Turbocompressor (TC)	$\dot{E}x_{D,TC} = \dot{m}_A \cdot \varepsilon_A + P_{TC,RE} - \dot{m}_B \cdot \varepsilon_B$	(17)
Turbine (TU)	$\dot{E}x_{D,TU} = \dot{m}_D \cdot \varepsilon_D - P_{TU,RE} - \dot{m}_E \cdot \varepsilon_E$	(18)
Regenerator	$\dot{E}x_{D,Reg} = \dot{m}_E \cdot \varepsilon_E + \dot{m}_B \cdot \varepsilon_B - \dot{m}_C \cdot \varepsilon_C - \dot{m}_F \cdot \varepsilon_F$	(19)
Component	Exergy efficiency	Eq.
Turbocompressor (TC)	$\eta_{x,TC} = \frac{\dot{m}_B \cdot \varepsilon_B - \dot{m}_A \cdot \varepsilon_A}{P_{TC,RE}}$	(20)
Turbine (TU)	$\eta_{x,TU} = \frac{P_{TU,RE}}{\dot{m}_D \cdot \varepsilon_D - \dot{m}_E \cdot \varepsilon_E}$	(21)
Regenerator	$\eta_{x,Reg} = \frac{\dot{m}_C \cdot \varepsilon_C - \dot{m}_B \cdot \varepsilon_B}{\dot{m}_E \cdot \varepsilon_E - \dot{m}_F \cdot \varepsilon_F}$	(22)

4. CO₂ operating parameters required for the analysis

Operating parameters of CO₂ (temperature, pressure and mass flow rate) in each operating point of the observed process from Fig. 1 and Fig. 2, are presented in Table 3. Specific enthalpies, specific entropies and specific exergies of CO₂ are calculated in each operating point by using NIST REFPROP 9.0 software [24].

Table 3. CO₂ operating parameters in each operating point

O.P.*	Temperature (°C)	Pressure (MPa)	Specific enthalpy (kJ/kg)	Specific entropy (kJ/kg·K)	Specific exergy (kJ/kg)	Mass flow rate (kg/s)
A	33.00	7.5	381.36	1.5937	217.07	50
Bis	100.88	22.5	415.77	1.5937	251.48	
B	102.57	22.5	419.59	1.6039	252.27	
C	321.48	22.5	749.84	2.3123	371.29	
D	550.00	22.5	1033.40	2.7159	534.55	
Eis	406.45	7.5	875.59	2.7159	376.73	
E	420.04	7.5	891.37	2.7389	385.65	
F	130.23	7.5	561.13	2.1218	239.39	

* O.P. = Operating Point (in accordance with Fig. 1 and Fig. 2)

In Table 3 are presented CO₂ operating parameters of the Turbocompressor (TC) and Turbine (TU) for both real and ideal processes. It can be observed that in an ideal (isentropic) process specific entropies are the same for operating points A-Bis (TC) and for operating points D-Eis (TU).

In Table 3 are presented specific exergies of CO₂ in each operating point at the base ambient state. For this analysis, the base ambient state is defined by the ambient pressure of 0.1 MPa and the ambient temperature of 25 °C.

5. Results and discussion

5.1. Energy analysis results

Turbocompressor (TC) is a mechanical power consumer. In ideal (isentropic) compression process, TC will use lower mechanical power (1720.5 kW) than in real (polytropic) compression process (1911.67 kW), Fig. 3.

Gas turbine (TU) is a mechanical power producer. In ideal (isentropic) expansion process TU will develop higher power (7890.5 kW) in comparison to real (polytropic) expansion process (7101.45 kW). Regardless if the expansion process is real or ideal, CO₂ will expand through the TU between the same pressures (between p_B and p_A), Fig. 2. Ideal (isentropic) compression or expansion processes assume always the same CO₂ specific entropy.

Mechanical power produced by TU will firstly be used for the TC drive. The rest of produced mechanical power by TU will be used for any mechanical power consumer drive (Useful power). If the TU and TC processes are ideal (isentropic), produced Useful power will be equal to 6170 kW, while in the real (polytropic) TU and TC processes, produced Useful power is equal to 5189.78 kW, Fig. 3.

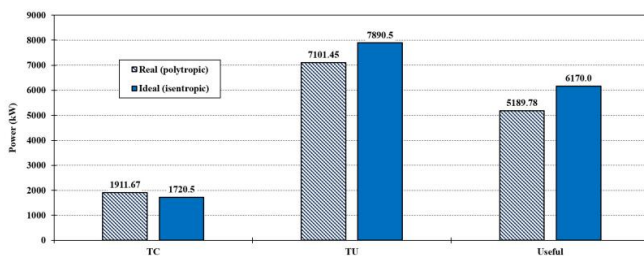


Fig. 3. Real (polytropic) and ideal (isentropic) mechanical power of Turbocompressor (TC), Turbine (TU) and Useful power

Transferred heat to CO₂ in Regenerator and Heater is equal to 16512.22 kW and 14178.12 kW, respectively (calculated by using Eq. 12 and Eq. 13, Table 1), Fig. 4. It is interesting and important to note that transferred heat to CO₂ in Regenerator is higher in comparison to Heater, what indicates significant influence of Regenerator on the delivered heat savings in Heater. Transferred heat from CO₂ to the cooling medium in Cooler (calculated by using Eq. 14, Table 1) is equal to 8988.33 kW.

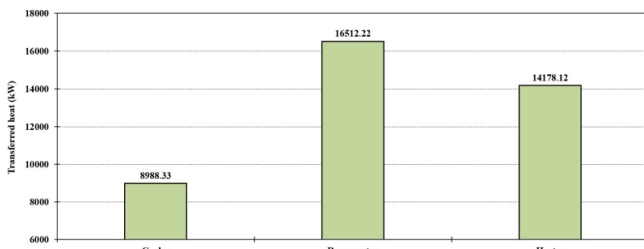


Fig. 4. Transferred heat to the cooling medium (in Cooler) and to operating medium (CO₂) in Regenerator and Heater

Energy efficiency of the whole observed cycle with the included Regenerator is 36.6% (calculated by using Eq. 15). Obtained energy efficiency of the CO₂ closed-cycle gas turbine is acceptable and is in the range with energy efficiencies of other open-cycle gas turbines. However, Regenerator inclusion in the observed closed-cycle is essential, without Regenerator (or in the case of Regenerator malfunction) energy efficiency of the analyzed CO₂

closed-cycle will be unacceptably low and equal to 16.91% (calculated by Eq. 16).

5.2. Exergy analysis results

Exergy analysis results at the base ambient state show that Turbocompressor (TC) has the lowest exergy destruction equal to 151.67 kW, while the Regenerator has the highest exergy destruction equal to 1362 kW, Fig. 5. In the exergy analysis of many systems [25, 26] is shown that, in general, exergy destruction and exergy efficiency of the components are reverse proportional. For the analyzed CO₂ closed-cycle gas turbine, Regenerator which has the highest exergy destruction of all observed components has also the lowest exergy efficiency (81.38%). However, reverse proportionality is not valid for the TC (which has the lowest exergy destruction, but not the highest exergy efficiency). The highest exergy efficiency of all observed components has Turbine (TU) equal to 95.39% (TC has a slightly lower exergy efficiency equal to 92.07%).

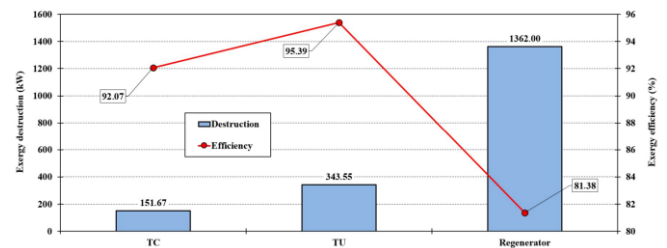


Fig. 5. Exergy destruction and exergy efficiency of TC, TU and Regenerator (base ambient state)

Regenerator influence on the observed CO₂ closed-cycle gas turbine is crucial. Therefore, for the Regenerator is investigated how the change in the ambient temperature influences its exergy destruction and exergy efficiency. Analyzed CO₂ closed-cycle gas turbine did not have any connection with the environment, but change in the ambient conditions (primarily the change in the ambient temperature) can have a notable influence on the exergy analysis parameters. During the ambient temperature change, the ambient pressure remains the same as at the base state (0.1 MPa).

Regenerator will achieve the highest exergy efficiency and the lowest exergy destruction (equal to 83.98% and 1270.5 kW) if the whole system operates at the lowest observed ambient temperature (in this analysis the lowest observed ambient temperature is 5 °C), Fig. 6. Increase in the ambient temperature will result with an increase in Regenerator exergy destruction and with a simultaneous decrease in Regenerator exergy efficiency.

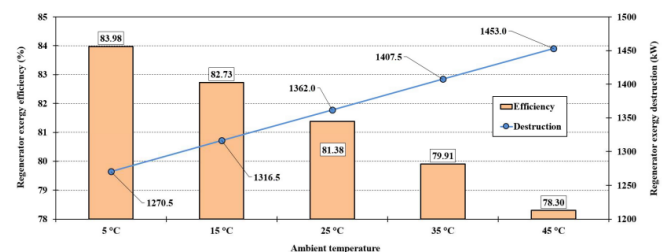


Fig. 6. Exergy destruction and exergy efficiency of Regenerator during the change in the ambient temperature

Further analysis of the observed CO₂ closed-cycle gas turbine will be based on finding optimal operating parameters in all operating points by using various artificial intelligence methods [27-30].

6. Conclusions

In the presented research is performed energy and exergy evaluation of CO₂ closed-cycle gas turbine. It is calculated main operating parameters of the whole observed cycle, as well as of each of its constituent components. For the Regenerator, as a crucial component of the analyzed process, is also performed variation in the ambient temperature. The main conclusions are:

- Useful real mechanical power of the observed process which will be used for mechanical power consumer drive is 5189.78 kW.
- Transferred heat to CO₂ in Regenerator is higher in comparison to Heater, what indicates significant influence of Regenerator on the delivered heat savings in Heater.
- Heat Regenerator is a crucial component of the observed CO₂ closed-cycle gas turbine. With Regenerator, overall cycle energy efficiency is equal to 36.6%, while without Regenerator (or if the Regenerator malfunction occurs) overall cycle energy efficiency will be equal to only 16.91%.
- From the exergy aspect, Turbocompressor (TC) has the lowest exergy destruction equal to 151.67 kW (when compared to Turbine and Regenerator), while the Turbine (TU) has the highest exergy efficiency equal to 95.39% of all three observed components.
- The ambient temperature variation shows that Regenerator will have the highest exergy efficiency and the lowest exergy destruction at the lowest observed ambient temperature of 5 °C (equal to 83.98% and 1270.5 kW, respectively).

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