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Plinske turbine in plinske elektrarne

Gas Turbines and Gas Cycle Plants

MATIJA TUMA

Prednosti plinskih postrojev

Plinske elektrarne postajajo pomembnejše šele v novejšem času, potem ko so bili razviti materiali za visoke temperature, katerim je izpostavljen predvsem prvi venec turbinskih lopat. Plinske elektrarne ne morejo nadomestiti fosilnih in jedrskih, pač pa jih zelo dobro dopolnjujejo, na primer pri pokrivanju dnevnih in letnih primanjkljajev električne energije. V posebnih okoliščinah: ob pomanjkanju vode, cenenem gorivu ali slabem električnem prenosnem omrežju so sodobni plinski postroji povsem konkurenčni parnim postrojenjem. V Sloveniji imamo v Brestanici tri plinske postroje in dva v Trbovljah. Značilnost plinskega postroja je, da potrebuje za vsak vgrajeni kW električne moči - v nasprotju z elektrarnami na fosilna goriva ali jedrskimi elektrarnami - majhna investicijska in velika obratovalna sredstva.

Plinski postroji imajo v primerjavi s parnimi postrojenji nekaj velikih prednosti:

– kratek rok dobave,

– majhen potrebni prostor za postavitev (plinski postroji: 10 do 20 m^2/MW, parna postrojenja enake moči: 50 do 80 m^2/MW),

– nizka specifična cena v ECU/kW, ki je le 0,5 do 0,3 specifične cene parnega postroja,

– ne potrebujejo hladilne vode,

– ni pepela,

– kratek zagonski čas (normalni čas zagona do polne moči: 14 do 20 minut, v posebnih primerih le 5 minut),

– majhna lastna raba energije (pod enim odstotkom, če ne upoštevamo energije za kompresor),

– preprosto upravljanje in

– majhno število zaposlenih.

Plinski postroji pa imajo v primerjavi s parnimi postrojenji tudi nekaj pomanjkljivosti:

– terjajo zelo dobra in draga goriva, npr.: zemeljski plin ali lahko kurilno olje,

– imajo slabši toplotni izkoristek in s tem slabši skupni izkoristek, od parnih postrojenj,

– zaradi visokih temperatur imajo nekateri deli plinskega postroja omejeno dobo trajanja.

Advantages of Gas Turbines

Gas cycle plants have only recently become more important with the development of materials for very high temperatures appearing in the first stage of turbine blades. Gas cycle plants cannot replace power plants fired by fossil or nuclear fuel but they can be very useful, for example, for covering daily or seasonal peak power demand. In special cases, such as a shortage of cooling water, cheap fuel or a deficient network, modern gas cycle plants are quite competitive with steam power plants. In Slovenia, there are five gas turbines: three at Brestanica and two at Trbovlje. Gas turbines, in contrast to conventional or nuclear power plants demand small capital and large operating costs.

In comparison to steam power plants, gas turbines have a number of considerable advantages:

– short delivery time,

– small building area (gas turbines: 10 to 20 m^2/MW, steam power plants: 50 to 80 m^2/MW),

– low specific cost ECU/kW is only 0,5 to 0,3 of the specific cost for a steam power plant,

– no need for cooling water,

– no ashes,

– short starting time (normal time for reaching full load: 14 to 20 minutes, in special cases only 5 minutes),

– small consumption of energy (less than 1 %, not counting the energy for the compressor),

– simple control,

– small number of employees.

In comparison to steam power plants, gas turbines also have a few disadvantages:

– they require expensive high quality fuel such as natural gas or light fuel oil,

– lower thermal efficiency and therefore lower overall efficiency than steam power plants,

– limited life time for some parts, due to extremely high temperatures.

Plinska turbina in okolje

Izpušni plini iz plinske turbine imajo visoko temperaturo in jih je zato mogoče koristno uporabiti:

– delno ekspandirani plini so lahko namenjeni za komprimirani in predgreti zrak pri zgorevanju fosilnih goriv v parnih kotlih, ki delujejo pri atmosferskem tlaku ali pri višjih tlakih: ta možnost je zanimiva, na primer, za parne kotle na zgorevanje v lebdeči plasti pod tlakom, kar znanstveniki zelo pospešeno raziskujejo;

– ekspandirani plini imajo visoko temperaturo, zato se lahko uporabijo za proizvodnjo pare za pogon parne turbine v posebnem prenosniku toplote – uparjalniku (utilizatorju); v tem primeru je moč parne turbine 1/3 do 1/2 moči plinske turbine.

Plinski postroji so tisti, ki so od vseh toplotnih postrojev najbolj sprejemljivi za okolje, zato so zelo perspektivni. Prvi plinski postroj na svetu je bil postavljen v kraju Neuchatel v Švici leta 1939 in zadovoljivo deluje še dandanes, po več ko 50 letih! V drugi svetovni vojni so se iz teh prvih plinskih postrojev razvili letalski potisniki – – reakcijski motorji in doživeli v letih po vojni nesluten razmah. Pri zgorevanju fosilnih goriv: črni premog, rjavi premog, nafta, zemeljski plin, se sproščajo na enoto proizvedene energije količine CO_2 v razmerju 100 : 121 : 88 : 58. Pri plinskem postroju, ki je kurjen z zemeljskim plinom, se torej sprošča približno dvakrat manj ogljikovega dvokisa kakor pri enako močnem parnem postrojenju, ki je kurjeno z rjavim premogom. Strokovnjaki trdijo, da je prav ogljikov dvokis glavni povzročitelj »tople grede«. Prav tako je s plinskim postrojem z vbrizgavanjem pare ali vode v vroče pline pred vstopom v turbino mogoče doseči nizke vrednosti dušikovih oksidov NO_x 40 do 100 ppm; te vrednosti so nižje kakor pri fosilnih elektrarnah enake moči. Če v plinskem postroju kurijo tekoče gorivo, potem je treba računati s SO_2, če pa gre za zemeljski plin, je delež žveplovega dvokisa v izpušnih plinih praktično zanemarljiv.

Plinsko-parna postrojenja

Izpušni plini iz plinskega postroja imajo po navadi temperaturo nekaj nad 500 °C, to pa je prav temperatura, primerna za parni proces. Zato je razumljivo, da prinaša povezava plinskega procesa s parnim v kombinirani plinsko-parni proces občutno izboljšanje celotnega izkoristka. Tak kombinirani plinsko-parni proces doseže povprečni letni izkoristek postrojenja več ko 50 %. Z drugimi besedami: več ko polovica v postrojenja dovedene energije v obliki toplote se spremeni v električno energijo.

A Gas Turbine and the Environment

Exhaust gases from a gas turbine can still be utilized due to their high temperature:

– partly expended gases can be used instead of compressed and preheated air for fossil fuel combustion in steam boilers, working at normal or elevated pressure; this possibility is convenient for steam boilers on fluidized bed combustion, which is now being intensively researched.

– exhaust gases can be used for the production of steam for a steam turbine in a special heat exchanger (utilizer); in such a case, the steam turbine power is 1/3 to 1/2 of the gas turbine power.

Gas turbines are the most environmentally acceptable of all thermal power plants, and are therefore very promissing for the future. The first gas turbine was built in the town of Neuchatel, Switzerland in 1939 and is still running satisfactorily today after 50 years.

The first jet engines were developed from these gas turbines during the second world war and experienced great evolution in the following years. The amount of CO_2 per unity of energy produced during the combustion of the fossil fuels, black coal : brown coal : oil : natural gas, is in the proportion 100 : 121 : 88 : 58. A gas turbine fired by natural gas produces only half of the amount of CO_2 produced by a steam power plant of the same power fired by brown coal. It is stated by experts that carbon dioxide is responsible for the formation of the »hot bed«. Low values for nitrogen oxides NO_x concentration of 40 to 100 ppm can also be achieved by the injection of steam or water into the stream of hot gases entering a gas turbine; these values are lower than those achieved by power plants of the same power fired by fossil fuels. If gas turbine is fired by fuel oil, the production of SO_2 must be taken into account while in the case of natural gas the content of SO_2 is practically negligible.

Combined Cycle Power Plant

The temperature of the exhoust gases from a gas turbine is usually a little above 500 °C, which is exactly suitable for a steam cycle. It is therefore evident that a combination of a gas and steam cycle considerably improves the overall efficiency. The annual efficiency of such a combined cycle exceeds 50 %. In other words: more than a half of the energy supplied to the plant in the form of heat is transformed to electricity. No other thermal machine is capable

Tako dobre predelave toplote v električno energijo ne doseže noben drug toplotni stroj! Slovenija se lahko pohvali, da je bilo prvo tako kombinirano plinsko-parno postrojenje postavljeno že skoraj pred 20 leti, to je v času, ko se tudi v razvitem svetu še niso povsem zavedali pomembnosti takih kombiniranih postrojenj. Zasluge za postavitev takega sodobnega plinsko-parnega postrojenja ima prav gotovo prof. Boris Černigoj, tedanji profesor za parne in plinske turbine na Fakulteti za strojništvo v Ljubljani.

Konferenca o plinskih turbinah in plinskih elektrarnah na Bledu

O naštetih problemih in lastnostih plinskih turbin in plinskih elektrarn je bil govor na mednarodni konferenci na Bledu 27. in 28. maja letos. Konferenco je organizirala Fakulteta za strojništvo Univerze v Ljubljani. Čeprav je šlo za dokaj specializirano posvetovanje, se ga je udeležilo okrog 120 strokovnjakov iz Slovenije, iz več drugih evropskih držav in iz Kanade. Referati na konferenci so bili razdeljeni na 6 tematskih skupin: energetika Slovenije, plinske turbine, nove tehnologije, smeri razvoja glede na varstvo okolja, plinsko-parna postrojenja, hkratna proizvodnja električne energije in toplote ter posodobitev sedanjih postrojev.

V uvodnem delu so konferenco o plinskih turbinah in plinskih elektrarnah pozdravili *Boris Sovič*, državni sekretar za energetiko v Ministrstvu za gospodarske zadeve; *dr. Miloš Komac*, vodja Oddelka za znanost pri Ministrstvu za znanost in tehnologijo, *prof. dr. Peter Novak*, dekan Fakultete za strojništvo in *Jože Kelnerič* z Zveze strojnih inženirjev in tehnikov Slovenije.

V razširjenem delu konference *»Energetika Slovenije«* je bilo prikazano stanje energetike v Sloveniji, njen pretekli in prihodnji razvoj. Predavanja so bila izbrana tako, da so poslušalci dobili zaokroženo sliko razvoja energetike v Sloveniji. Iz prikazanega je bilo razvidno, da bo zemeljski plin igral pomembno vlogo v prihodnjem energetskem razvoju države, ki se po ocenah strokovnjakov lahko naslanja le na premog in zemeljski plin. Pri spreminjanju kemično vezane energije primarnih energijskih virov v električno energijo in toploto – to sta namreč tisti vrsti energije, ki ju človeštvo potrebuje za vsakdanje življenje – je zemeljski plin daleč najbolj prijazen okolju. Pri zgorevanju zemeljskega plina se sprošča na enoto proizvedene energije najmanj ogljikovega dvokisa, zanemarljivo malo žveplovega dvokisa in razmeroma malo dušikovih oksidov. Vsi drugi primarni viri energije so v tem pogledu okolju manj prijazni.

of a such efficient transformation. It is noteworthy that the first combined cycle power plant was built in Slovenia almost 20 years ago at a time when even experts in the developed world were not quite aware of the importance of this type of power plant. The major credit for the construction of this modern combined cycle plant goes to Prof. Boris Černigoj, then professor for gas and steam turbines at the Faculty of Mechanical Engineering of Ljubljana.

The Symposium on Gas Turbines and Gas Cycle plants at Bled

The mentioned problems and characteristics of gas turbines and gas cycle plants were the theme of an international symposium held at Bled, May 27 to 28, this year. The Symposium was organized by the University of Ljubljana, Faculty of Mechanical Engineering. Although it was quite a specialized meeting, it vas attended by approximately 120 experts from Slovena, other European countries and Canada. Papers were divided into 6 sections: Energy and Power in Slovenia, Gas Turbines, New Plant Technologies, Environmental Trends, Gas-Steam Power Plants and Cogeneration and Plant Improvements.

In the introductory part, the Symposium on Gas Turbines and Gas Cycle Plants was welcomed by *Boris Sovič*, State Secretary of the Department of Energy at the Ministry of Economic Affairs, *Dr. Miloš Komac*, the Head of Department of Science at the Ministry of Science and Technology, *Prof.Dr. Peter Novak*, Dean of the Faculty of Mechanical Engineering of Ljubljana and *Jože Kelnerič*, of the Society of Engineers and Technicians of Slovenia.

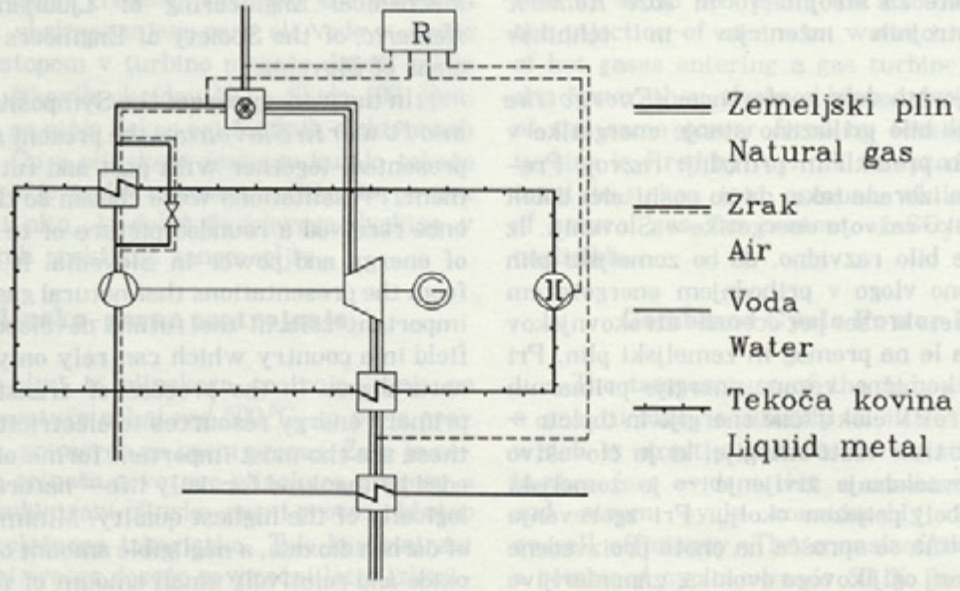
In the plenary part of the Symposium, *»Energy and Power in Slovenia«*, the present situation was presented, together with past and future development. Presentations were chosen so that the audience received a rounded picture of te development of energy and power in Slovenia. It was evident from the presentations that natural gas will play an important role in the future development of this field in a country which can rely only on coal and natural gas. In the process of transformation of primary energy resources to electricity and heat – these are the most important forms of energy needed by mankind for daily life - natural gas is ecologically of the highest quality. Minimum amounts of carbon dioxide, a negligible amount of sulphur dioxide and relatively small amount of nitrogen oxides are emitted during the combustion of natural gas. All other primary energy resources are less environmentally acceptable from this point of view.

Tematska skupina »*Plinske turbine*« je bila najobširnejša in je obsegala 8 referatov: 4 domače in 4 tuje. Med drugim so v njih poročali o rezultatih več doktorskih del (Inštitut za mehaniko Univerze v Hannovru, Nemški inštitut za letalsko in vesoljsko tehniko iz Kölna, Tehniška fakulteta Univerze v Mariboru).

V tematski skupini »*Nove tehnologije*« so bili 4 referati: 3 iz tujine in 1 iz Slovenije. Poročali so o tehnični novosti v svetovnem merilu: plinski krožni proces z vmesnim krogom, v katerem je delovna snov zmes tekočega natrija in kalija NaK78 (sl. 1). Vmesni krog s tekočo kovino, pri delovnem tlaku nekaj več ko 1 bar, je zaprt, pri tem je tudi elektromagnetna črpalka popolnoma zaprta in nima gibajočih se delov. Bistvena prednost postroja z vmesnim krogom na tekoče kovine je zelo visok izkoristek in njegova odlična prilagodljivost trenutnim potrebam po toploti. Z elektromagnetno črpalko je namreč mogoče zvezno spreminjati pretok zmesi natrija in kalija v vmesnem krogu; s tem se tudi zvezno spreminja toplotni tok, ki je namenjen ogrevanju, na račun toplotnega toka za regeneracijo in nasprotno. V referatih je bil podrobneje obdelan plinski postroj električne moči 10 MW, ki pri čisti proizvodnji električne energije dosega izkoristek 35 %. Z izkoriščanjem toplote dimnih plinov za ogrevalne namene pa je mogoče koristno pridobiti še 13 MW toplote; pri taki hkratni proizvodnji električne energije in toplote se izkoristek povzpne na 82 odstotkov. Zaradi regeneracije je tlak za kompresorjem samo 6 bar, kar je precej manj, kakor so tlaki v današnjih plinskih postrojih. Pri tem se spreminja temperatura

The section »*Gas Turbines*« was the larges and consisted of 8 presentations, 4 domestic, 4 foreign. They included reports of the results of a number of disertations (University of Hannover — Institute of Mechanics, Germany; DLR — Institute for Propulsion, Köln, Germany; University of Maribor, Faculty of Technical Sciences, Slovenia).

The section »*New Plant Technologies*« consisted of 4 presentations, 3 foreign and 1 from Slovenia. A world technical innovation was reported: a gas cycle containing a mixture of liquid natrium and kalium NaK78 (Figure 1). The inner cycle, with liquid metal and a working pressure a little above 1 bar, is closed; even the electromagnetic pump is completely closed and has no moving parts. The main advantages of the cycle with an inner cycle are very high efficiency and excellent adaptability to momentary need for heat. The electromegnetic pump allows the mass flow of the natrium-kalium mixture to be smoothly varied; this causes a variation of the heat flow for heating at the expense of the heat flow for regenerative heating of working air and vice versa. One of papers presented in detail a gas turbine with electrical power of 10 MW, achieving 35 % efficiency only by producing electricity. Using the heat of the exhoust gases for heating purposes, an additional 13 MW of heat can be obtained; such simultaneous production of power and heat leads to an everall efficieny of 82 %. Due to regeneration, the pressure on the exit from the compressor is only 6 bar, which is rather less than in other modern gas turbines. The temperature of



Sl. 1. *Plinski postroj z vmesnim krogom na tekoče kovine.*
Fig. 1. *Gas turbine with an inner cycle containing liquid metal.*

izpušnih plinov za prenosnikom toplote plin/tekoča kovina od 330 do 537 °C. Pri takih plinskih postrojih z regeneracijo so dosegljivi izkoristki do 40 odstotkov, kar je precej več od izkoristkov današnjih običajnih plinskih postrojev brez regeneracije. V tem skupnem projektu sodelujejo RWE Essen, ki podpira projekt finančno, Siemens Bergisch Gladbach, ki daje znanje o tekočih kovinah, EGT Essen, ki prispeva modificirani plinski postroj, in Fakulteta za strojništvo Ljubljana, ki je računalniško obdelala in optimirala predelavo kompresorja plinske turbine. Prav gotovo je ta del predavanj, ki doslej še ni bil nikjer objavljen, najpomembnejši dosežek konference.

V tematski skupini *»Smeri razvoja glede na varstvo okolja«* je bilo zbranih 5 referatov: 4 iz tujine in 1 iz Slovenije. Z aplikativnega in razvojnega vidika je bilo poročano o tehničnem napredku zgorevanja v gorilnikih plinskih postrojev in možnosti za nadaljnje zmanjševanje deleža NO_x v izpušnih plinih plinskih turbin.

V tematski skupini *»Plinsko-parni postroji ter hkratna proizvodnja električne energije in toplote«* so bili 4 referati: 3 iz tujine in 1 iz Slovenije. Predstavljen je bil napredek s tehničnega in z gospodarskega vidika na področju, ki je v svetu in pri nas zelo aktualno in omogoča najvišji skupni izkoristek spreminjanja primarne energije v sekundarno.

V tematski skupini *»Posodobitev sedanjih postrojev«* so bili z industrijskega vidika prikazani dosežki, ki omogočajo ekonomsko upravičeno posodobitev in podaljšanje dobe trajanja sedanjih plinskih postrojev. Tematska skupina je obsegala 5 referatov: 3 iz tujine (Siemens -Erlagen, MAN Gutehoffnungshütte - Oberhausen, Westinghouse Canada - Hamilton/Ontario) in 2 iz Slovenije.

Referati so bili izdani v zborniku z naslovom »Proceedings of The International Symposium »Gas Turbines and Gay Cycle Plants«, ki obsega 430 strani. Konferenca je v tehničnem pogledu dosegla uspeh, prav tako se je posrečila tudi predstavitev Slovenije. Po oceni nekaterih tujih strokovnjakov, ki so prišli na Bled naravnost s podobne konference v ZDA, je konferenca o plinskih turbinah in plinskih elektrarnah na Bledu po strokovni in po organizacijski plati povsem primerljiva z ameriško.

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metal varies from 330 to 537 °C. This type of gas turbine with regeneration can achieve an efficiency of 40 %, which is much more than the efficiencies of other modern gas turbines with no regeneration. This project was financially supported by RWE - Essen, knowhow about liquid metals was provided by Siemens - Bergisch Gladbach, European Gas Turbines - Essen supplied the modified gas turbine and the Faculty of Mechanical Engineering of Ljubljana performed the computer optimization of the modified compressor for the gas turbine. This package of papers, which had never been presented elsewhere, is certainly the most important achievement of the Symposium.

The section, *»Environmental Trends«*, consisted of 5 papers, 4 foreign and 1 from Slovenia. Technical progress in the applicability and development of combustion in burners for gas turbines and the possibility of further minimization of NO_x content in the exhaust gases of gas turbines were reported.

The section, *»Gas–Steam Power Plants, Cogeneration«*, consisted of 4 papers, 3 foreign and 1 from Slovenia. Technical and economic progress was presented in a very topical field in the world, results which allow the highest overall efficiencies in the transformation of primary energy to secondary.

The section, *»Plant Improvements«* , consisted of 5 papers, 3 foreign (Siemens-Erlangen, MAN Gutehoffnunggshütte - Oberhausen, Westinghouse Canada - Hamilton/Ontario) and 2 from Slovenia, presenting the achievements permitting economically justified renewal and the prolongation of the lifetime of existing gas turbines.

The papers were published in the Proceedings of The International Symposium »Gas Turbines and Gas Cycle Plants«, consisting of 430 pages. The symposium was a success from a technical point of view and as a promotion of Slovenia. Some of the foreign experts coming to Bled directly from a similar symposium held in USA, pointed out that the contents and the organization of the Symposium »Gas Turbines and Gas Cycle Plants« was directly comparable to the one in USA.

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