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Tehnološke zahtevnosti pri izdelavi plinskega odvodnika

A Precision Techniques for Gas-Arrester Manufacturing

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Plinski odvodniki so hermetično zaprte celice, v katerih je med okrovom in elektrodo ujet argon ali njegova mešanica s primernim drugim žlahtnim plinom. Ob določenih pogojih (napetostni udar) plin lahko ionizira in s tem postane celica električno prevodna. Plinski odvodnik večjih moči, kakršnega razvijamo, je s še drugimi električnimi elementi povezan v sklop, ki deluje zaščitno, tako da omogoči takojšen odvod toka strele v zemljo. Čeprav je konstrukcija na videz preprosta, saj celoto sestavljajo le štirje glavni sestavni deli, je pa izdelava dokaj zahtevna. Za zagotavljanje čistosti in ohranjanje nespremenljivega tlaka plina v celici je treba uporabiti metode vakuumsko tesnega spajanja, ki so podobne onim pri proizvodnji elektronskih cevi.

V prispevku predstavljeni postopki so: izdelava spojev steklo - kovina, testiranje tesnosti in trdo spajkanje v zaščitni atmosferi. Na kratko je opisan razvoj tehnoloških postopkov do sedanjega stanja in nakazane so možnosti za zmogljivejšo opremo za industrijsko proizvodnjo.

(Ključne besede: odvodniki plinski, spoji steklo-kovina, preskušanje tesnosti, spajkanje trdo)

Gas arresters are hermetically sealed cells in which argon, or a mixture of argon and another noble gas, is captured between two isolated electrodes. Under defined conditions (e.g. lightning strike, etc.) it can become ionised, i.e. capable of conducting an electric current. The gas arrester designed for higher powers that has been developed in our laboratory is connected with other electro-elements in a special device that acts protectively in such a way that it diverts the lightning strike to the earth. The construction of the cell is relatively simple: no more than four main pieces are joined in a compact compound, but the procedures are not simple. To ensure high levels of cleanliness and required constant gas pressure in the cell for a period of years, it is necessary to use methods of vacuum-tight joining that are similar to those used for electron-tube production.

In this paper the presented techniques are the manufacturing of glass-to-metal joints, leak detection and hard brazing in an inert atmosphere. A short description of the technology developed so far and the capabilities for more productive equipment are also given.

(Keywords: gas arresters, glass-to-metal joints, tighteness tests, brazings)

0 UVOD

Strele, preklopna rokovanja v stikalnih postajah v spletu porabnikov električne energije in drugi nenačrtovani pojavi povzročajo v električnem omrežju udarne sunke in valovanja. Posledica so prenapetosti, ki v priključenih električnih napravah (računalniki, telefoni, hi-fi instrumenti, itn.) lahko povzročijo poškodbe. Obramba pred njimi so zaščitne naprave, ki se jih vgrajuje v razdelilne omarice na vstopu električne mreže v stavbe. Njihov pomemben sestavni del so prenapetostni odvodniki, med katerimi zavzemajo posebno mesto plinski odvodniki.

0 INTRODUCTION

Switching manipulations in an electrical network caused by electric consumers, lightning and other unexpected phenomena cause waves and strikes in the network. The results are overvoltages, which can damage sensitive electrical equipment: like computers, telephone apparatus, hi-fi devices etc. The defense against such phenomena is protection elements that are built into electric installations at the points (distribution boxes) where buildings are connected to the network. The important components of these elements are overvoltage

Prednost plinskih pred drugimi vrstami odvodnikov je v tem, da so majhni po prostornini ter da v njih ostajata plazma in oblok zaprta v celici (ognjevarnost). Razvoj, katerega glavni namen je v prvi fazi nadomestiti uvoz tujih elementov, je zelo interdisciplinaren, saj povezuje znanosti o materialih, o plazmi ter elektrotehniko in že na svojem začetku kaže, da bo ključno za uspeh prav postavljanje tehnoloških postopkov izdelave.

1 KONSTRUKCIJA CELICE

Plinski odvodnik, kakršnega razvijamo (sl.1), je sestavljen iz lončastega telesa, ki mu odprtino na vrhu zapira strnjen sklop iz kovinskega obročka, stekla in osrednje elektrode, imenujemo ga prevodnica ali vtalek. V celici je še tableta barijevega klorida in izbrana plinska mešanica. S steklom ločena lonček in osrednji del prevodnice sta elektrodi, med katerima pride do preboja.Vsi spoji med različnimi materiali in sestavnimi deli morajo biti hermetično tesni.

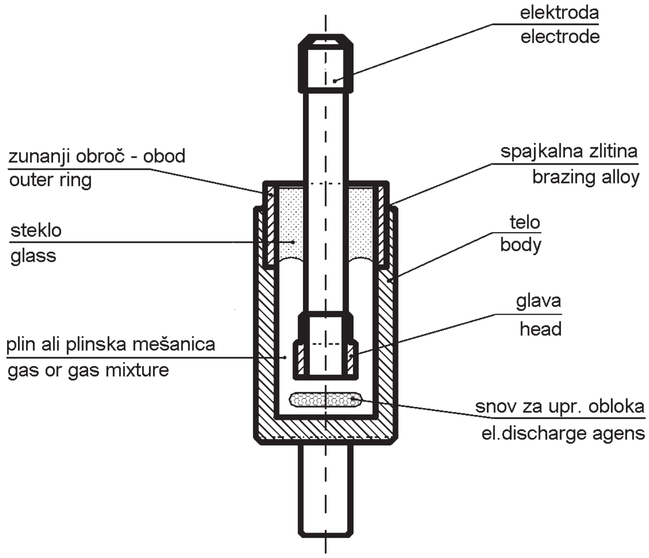
Lončasto telo in obod stekla sta iz jekla oziroma iz posebne zlitine, elektroda iz molibdena, steklo je posebno s termičnim raztezkom, ki je prilagojen raztezkom molibdena in obodnega kovinskega obroča. V izdelavnem postopku sta posebej pomembna dva koraka. Prvi korak je zahtevna izdelava prevodnice z dvema spojema steklo-kovina; postopek je naslednji: na grafitni podstavek zložene sestavne dele (obroček, steklena predoblika in elektroda) segrejemo v peči na okoli 1000 °C, steklo se stali in oprime pripravljenih kovinskih površin. Drugi (in zadnji) korak je zatalitev te prevodnice s trdo spajko (zlitina srebra in bakra) v ležišče telesa. Pri obeh omenjenih korakih je glavna zahteva tesnost izdelanega spoja; še posebej je skrb za tesnost pomembna ob temperaturnih spremembah v drugem koraku (spajkanje), da se ne poškoduje že prej izdelani

arresters, and among them a special place is reserved for so-called gas arresters because they are small and because the plasma is always captured in a cell, which means they cannot result in burning. The main goal of our activities is to reduce our dependence on the importation of these elements. Initial development efforts have focused on tackling the difficult precision techniques for gas-arrester finishing.

1 CELL DESIGN

The gas arrester we are developing now (Fig. 1) is composed of a metal pot that is closed at the top with a special feedthrough. The feedthrough is made of a ring, containing a central electrode that is sealed to both pieces with glass. The pot and the feedthrough are brazed together using a silver brazing alloy. In the cell interior there is a tablet of barium chloride, and a selected gas mixture is also trapped inside. All the joints between the different materials or pieces have to be sealed hermetically.

The central electrode and the pot represent two poles isolated by glass, and between them an electric arc appears under defined conditions. The pot and the ring are made of steel or a special alloy, and the electrode is made of molybdenum; the glass is special in terms of its thermal dilatation and has to accommodate the dilatations of the inner molybdenum electrode and the metal ring. There are two basic design steps in the manufacturing procedure. The first step is feedthrough finishing: the electrode, the glass perform and the outer ring are placed on the centering tool, and then by melting the glass at high temperature the central electrode and the outer ring are coupled together into a compact element. The second and final step is brazing the feedthrough into the pot. The main difficulty with both operations is



Sl. 1. *Shema plinskega odvodnika*
Fig. 1. *Scheme of gas arrester*

spoj steklo-kovina v prevodnici. Nujno je torej treba preverjati tesnost, za kar obstajajo posebne testne metode.

Celoten postopek je seveda daljši, saj ga sestavlja cela vrsta opravil. Poleg že omenjene izdelave spojev steklo-kovina in zaprtja plina so to še naslednje: delo z vakuumskim sistemom na peči, nastavljanje temperaturnega režima pri spajkanju, doziranje čistih plinov, razplinjanje kovinskih delov, nanos galvanskih plasti, preverjanje tesnosti, spojev, izdelava spajkalnih obročkov in tablet $BaCl_2$, čiščenje in shranjevanje sestavnih delov, električni preizkusi itn. V naslednjem odstavku predstavljamo tri izmed omenjenih, ki so ključnega pomena za kakovost končnega izdelka.

2 ZAHTEVNI POSTOPKI IZDELAVE

2.1 Spoj steklo-kovina

Spoj steklo-kovina izdelamo tako, da hkrati segrevamo dotikajoča se kosa kovine in stekla na temperaturo, pri kateri postane steklo toliko zmehčano, da zalije in omoči površino kovine (ali zlitine). Osnova tovrstnim spojem je kovinski oksid, ki se v času dotikanja žareče kovine in staljene steklene mase kemijsko spoji z oksidnimi sestavinami stekla. Med ohlajanjem je najbolj ugodno, da se oba partnerja enako krčita, sicer pride do pokanja stekla. Spoje steklo-kovina delimo glede na toplotne raztezke obeh partnerskih materialov, na usklajene in neusklajene. Pri usklajenih (sl.2a) spojih združimo tâko steklo in tâko kovino oziroma zlitino, ki imata v vsem temperaturnem območju ista ali vsaj čim bolj enaka toplotna raztezka. Največ uporabljani usklajeni spoj se izdeluje iz zlitine, poznane pod imenom kovar (Fe-Ni-Co) in iz "kovarskega" stekla (npr. Schott 8250) z raztezkom $\alpha = 50 \times 10^{-7}$/K. Med neusklajenimi spoji je najširše uporabljan stisni spoj (sl. 2b), pri katerem je steklo z manjšim raztezkom ujeto v obroč kovine z večjim raztezkom. V tem primeru adhezija med kovinskimi oksidi in steklom ni toliko pomembna, kajti odgovornost za trdnost in tesnost spoja prevzame

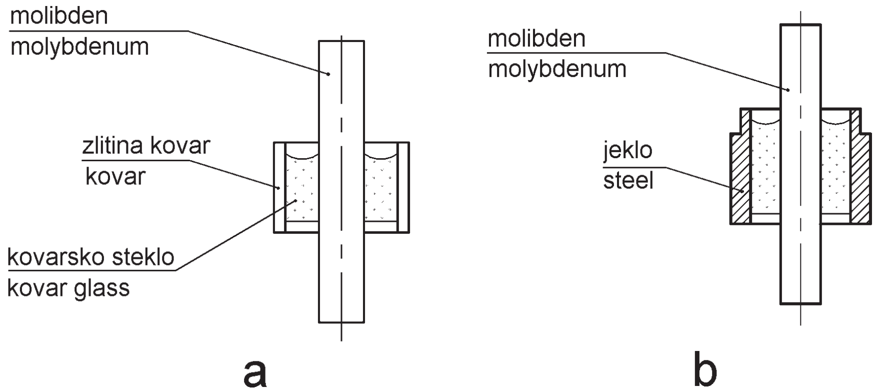
achieving a 100% hermeticity of the joint. During the second step it is important not to damage the very delicate glass-to-metal joint.

The whole procedure is longer than the mentioned two steps: it also involves many smaller steps. These steps include: braze-ring making, operating the vacuum system and the furnace, adjusting the profile of the brazing temperature, pure-gas metering, manufacturing glass-to-metal joints, encapsulation brazing, leak-detection of the seals and joints, keeping the components clean, electrical testing, etc. In the next section three especially important and interesting operations are presented.

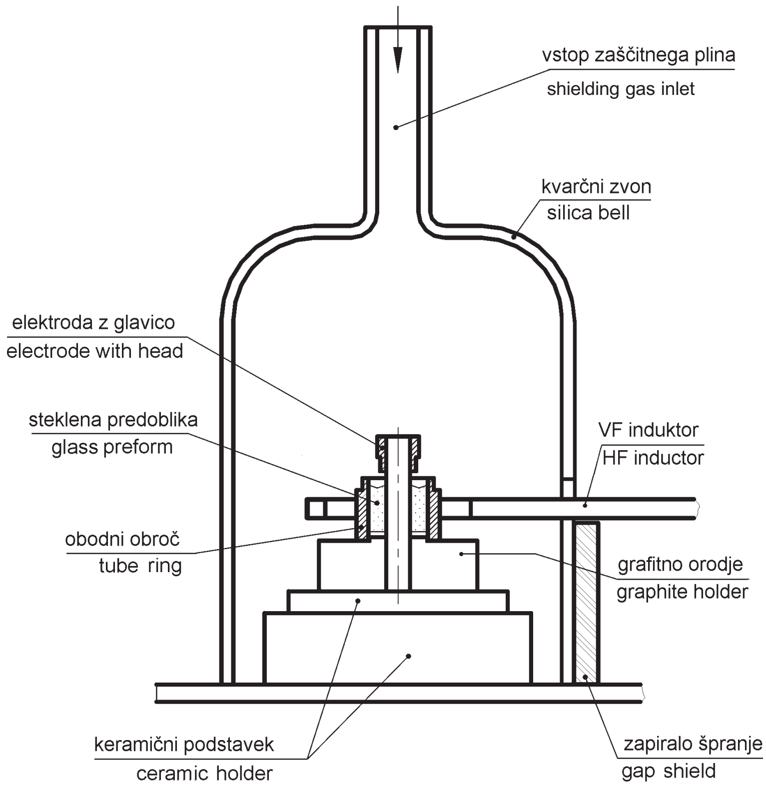
2 DEMANDING TECHNIQUES IN THE MANUFACTURING

2.1 Glass-to-metal joint

Glass-to-metal joints are made by simultaneously heating a piece of metal (or alloy) and a piece of glass that are in contact at the melting temperature of the glass. The principle of such a seal is the union of two sorts of oxides: the oxide of the metal piece firmly bonds the oxide components of the glass. This is realized during the time of full contact between the glowing metal and melted glass mass. During cooling it is very important that both parts contract in harmony, otherwise the in-built glass might break. Regarding the thermal extensions of the partner materials, there are two sorts of glass-to-metal joints, i.e. matched and unmatched. Matched ones (Fig. 2a) involve the joining of glass and metal (or alloy) with equal, or nearly the same, thermal expansions across the whole temperature range. The most commonly matched joints are manufactured from an alloy known as Kovar (Fe-Ni-Co) and of so-called "Kovar glass" (e.g. Schott 8250) with an expansion of $\alpha = 50 \times 10^{-7}$/K. The most frequent unmatched joint is the compressed joint (Figure 2b), where glass with a smaller expansion is caught in a metal ring that has a larger expansion. In this case the adhesion between the metal oxides and



Sl. 2. *Dve vrsti spoja steklo-kovina (a - usklajeni in b - neusklajeni)*
Fig. 2. *Two sorts of glass-to-metal joints (a-matched, b-unmatched)*



Sl. 3. *Izdelava prevodnice z visokofrekvenčnim segrevanjem v inertni atmosferi*
Fig. 3. *Feedthrough manufacturing using high-frequency heating in an inert atmosphere*

krčna sila obodne kovine, ki se pojavi po ohladitvi pri izdelavi spoja. Stisni spoj se največ uporablja za električne prevodnice, pri katerih skozi stisnjeno steklo poteka osrednje prevodno kovinsko steblo. Obodna prirobnica je navadno iz nerjavnega jekla ali železa z razteznostnim koeficientom 100 do 160 × 10^{-7}/K, steklo pa izberemo tâko, da ima koeficient okoli 90 × 10^{-7}/K. Na sliki 1 prikazani odvodnik je konstruiran z usklajenim spojem – zunanji obroč prevodnice je iz kovarske zlitine in uporabljeno steklo je kovarsko. V toku naših razvojnih dejavnosti izvajamo preizkuse tudi z izvedbo, ki ima stisni spoj.

Ene in druge spoje smo prvotno izdelovali z visokofrekvenčnim segrevanjem (sl. 3), sedaj pa prehajamo na staljevanje stekla (sl. 4) v peči. V obeh primerih zagotovimo potrebno odsotnost zraka (da ne pride do prevelike oksidacije) z uporabo inertne atmosfere. Zaščitni plin je navadno argon ali dušik, ki mu lahko dodamo 3 do 10 % vodika.

2.2 Preverjanje tesnosti

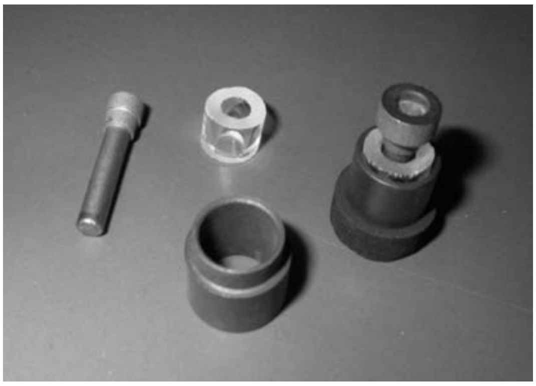
Eden glavnih pogojev za stabilno delovanje plinskega odvodnika je tesnost. Vsako puščanje ovojnice ima za posledico izgubo delovnega plina ali vdor zraka od zunaj, kar pomeni spremembo značilnosti elementa preko dopustnih meja. Prizadevanja za doseganje čim boljše tesnosti celice so torej razumljiva. Šteje se, da sestavni materiali ne prepuščajo plinov, nujno pa je treba preveriti tesnost oz. netesnost spojev.

the glass is not so important because the firmness and the tightness are achieved by the contracting force of the metal ring, which appears during cooling (in the last step of joint manufacturing). A compressed joint is normally used for electrical single- or multi-tip feedthroughs, where a glass insulator with a central conductive wire is placed in a metal wall. The outer metal is usually stainless steel with an expansion factor from 100 × 10^{-7}/K up to 160 × 10^{-7}/K; a suitable glass would have a factor of approximately 80 × 10^{-7}/K. The arrester shown in Fig.1 is made with Kovar and Kovar's glass, but we have also tried to develop a version with a compressed joint.

At the beginning of our development work both kinds of joints were produced using high-frequency heating (Fig. 3), in later experiments, however, we began to melt the glass (Fig. 4) in a furnace. In both cases the absence of air (to prevent oxidation) is achieved with an inert atmosphere.

2.2 Leak detection

Hermeticity is one of the first conditions for the stable operation of a gas arrester. The presence of a leak in the envelope causes a change of the gas composition (because air enters the chamber) and the arrester does not function appropriatelly. It is supposed that the component materials do not have leaks, but we need to test the quality of the joints.



Sl. 4. *Deli pripravljeni za izdelavo prevodnice s stalitvijo stekla*
Fig. 4. *Pieces prepared for feedthrough manufacturing*

V primeru odvodnika izdelujemo spoje dvakrat; najprej ko izdelujemo vtalek (spoj s steklom) in na koncu, ko zapremo plin (trdo spajkanje kovin). Spoj steklo-kovina je pri vtalku za odvodnik dokaj zahteven, saj se pojavlja v stisnem spoju na dveh mestih (znotraj ob molibdenu in zunaj proti obodnemu obroču), poleg tega pa je to spojno mesto kasneje (ob spajkanju) ponovno izpostavljeno temperaturi. Med razvojem preverjamo najprej tesnost vtalkov in ob končnih preverjanjih tudi tesnost izdelanega odvodnika.

Netesnost neke stene je podana s količino plina, ki vdre skozi netesno mesto v določenem času in pri določeni tlačni razliki z ene strani na drugo; enota je torej mbarl/s. Za natančna preverjanja tesnosti se uporablja plin helij, ki ima poleg vodika najmanjše molekule in hkrati ni eksplozijsko nevaren.

Pri proizvodnji vtalkov testiramo tesnost s helijevim masnim spektrometrom, in sicer tako, da preizkušanec vpnemo v primeren nastavek (orodje) in le-tega priključimo na testirno napravo, ki ima vgrajeno zaznavalo za helij. Nato izčrpamo prostor pod vtalkom in od zgoraj obpihavamo kritični spoj s tankim curkom helija (sl. 5). Če zaznavalo zazna dotok testnega plina, to pomeni, da je na mestu dotekajočega curka netesno mesto.

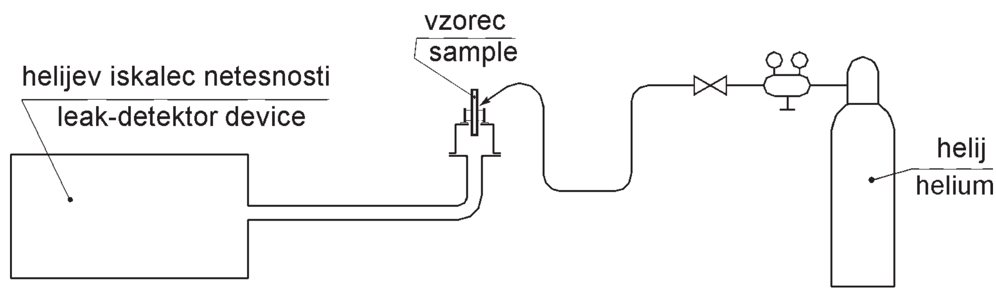
Pri testiranju končno izdelane celice je dostopna le ena stran spojev, druga pa ne. Zato izberemo metodo, imenovano "bombanje". V tem

In the case of gas-arrester manufacturing, two joints are present: at the glass-to-metal surfaces, at the brazed seal between the feedthrough and the body of the pot. A glass-to-metal joint is at two locations: inside, with molybdenum; and outside, with a metal ring. Therefore, there are three critical places where leaks can appear: twice at the glass-to-metal joint and once at the hard, brazed seal. The leak-detection on the three places is obligatory. It is also very necessary because of the delicate glass-metal area in the feedthrough, which is twice exposed to high temperatures, the second one during the brazing operation.

The leakage is expressed in terms of the quantity of gas (air) that flows through the leak during a particular time unit for a defined pressure difference from one side to another. The accepted unit for the size of a leak is mbarl/s. Usually, helium gas is used for such testing because it has the smallest molecules and is not explosive.

Gas-arrester feedthroughs are leak detected using a helium mass spectrometer, i.e. using a residual gas analyzer adjusted for the mass of helium. The sample has to be put in a suitable tool that is connected to the instrument. The space under the sample is then evacuated and on the upper side a narrow jet of helium gas is admitted to the critical places (Fig. 5). If the instrument senses a flow of test gas, it means that in the location of the jet there is a leak.

For finished cells only one side of the joints is accessible. Therefore, another method is chosen, known as bombing. In this case a sample cell must



Sl. 5. *Načelo iskanja netesnosti s helijevim masnim spektrometrom*
Fig. 5. *Principle of leak detection using a helium mass spectrometer*

Sl. 6. *Prvi del "bombanja"*
Fig. 6. *First step of bombing procedure*

primeru namreč v primerni bombici (sl. 6) izpostavimo preizkušanec tlaku helija (npr. 5 bar, dve uri), potem preskušano celico vzamemo ven, da se na okolnem zraku razplinijo zunanje površine (zračenje 1 do 2 uri), na koncu pa jo namestimo v komoro testirne naprave, ki zaznava helij. Če naprava ugotovi helij, je to znak, da le-ta prihaja skozi steno iz celice ali z drugo besedo, da je v steni netesnost.

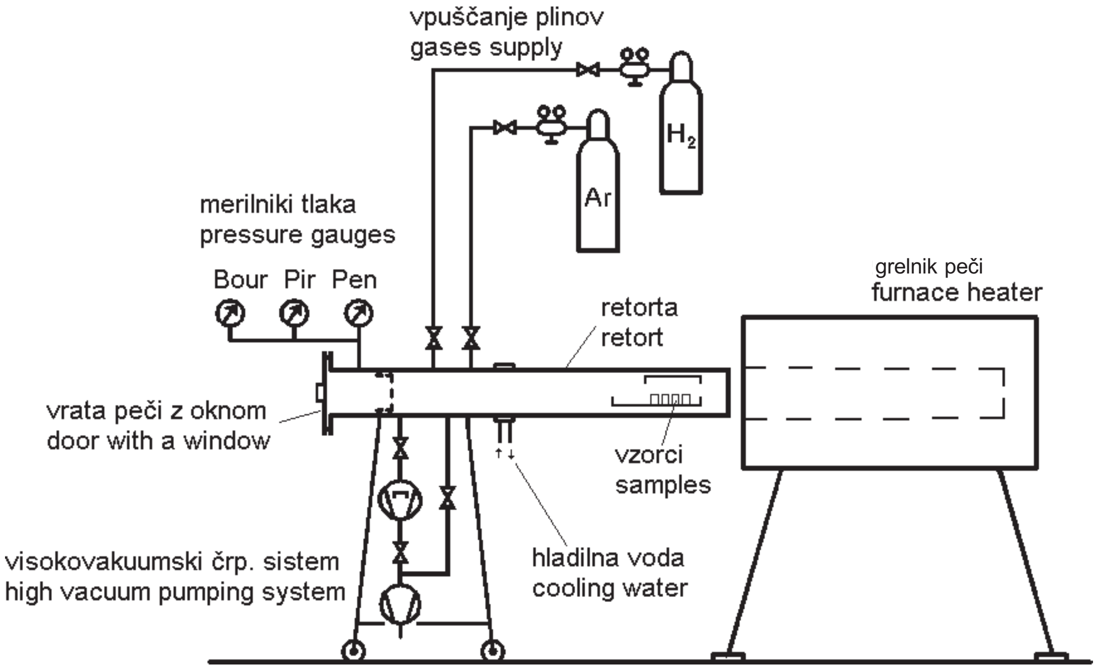
2.3 Zaprtje plina v celico

Končno zapiranje z zajetjem želenega plina v celico izvedemo v vakuumski peči, katero lahko prepihujemo oz. napolnimo z različnimi plini. Pri

be exposed (in a suitable bomb, Fig. 6) to a pressure of helium (e.g. 5 bar, 2 hours). Then the sample has to be ventilated (e.g. 1 to 2 hours) and after this it is placed in an evacuated vessel - a part of the leak detector that senses the helium. If the presence of the test gas is established, it means that the gas is coming from the cell through a gap, and a leak is present in the envelope.

2.3 Gas encapsulation

The final manufacturing operation is closing the cell, which has to ensure the hermeticity. This procedure is usually realized in a vacuum furnace



Sl. 7. *Inkapsulacija plina v poskusne odvodnike s spajkanjem v vakuumski peči*
Fig. 7. *Gas encapsulation in samples by hard brazing in a vacuum furnace*

našem razvoju smo uporabili retortno peč (sl. 7), ki je togo zvezana z visokovakuumskim sistemom na vozičku, tako da jo lahko kot celoto pomaknemo v grelno območje, ali pa jo potegnemo iz njega.

Elemente odvodnika (lonček, tableto klorida, vtalek in spajko) pravilno zložimo na podstavku na "ladjici", ki jo porinemo na določeno mesto v retorti; retorto nato zapremo in izpraznimo do tlaka $< 9 \times 10^{-5}$ mbar; med segrevanjem še vedno črpamo tako, da tlak pri tem ne naraste nad 2.10^{-4} mbar. Ko dosežemo 500 °C, prekinemo črpanje in vpustimo okoli 800 mbar argona (ali izbrane plinske mešanice). Nato nadaljujemo segrevanje do tališča spajke in ob njenem stečenju ostane plin ujet v celici. S tem je naš cilj dosežen.

Postopek je treba izpeljati tako, da se ne pokvari spoj steklo-kovina in da je spajkani spoj tesen. Pri tem je nemalo težav, ki jih odpravljamo z izkušnjami, pridobljenimi pri poskusih.

connected with a gas-supply unit. In our case we used a retort furnace connected to a transportable high-vacuum pumping station (Fig. 7), so it can be moved into or out of the heating zone.

The cleaned components of the gas arrester are precisely put together on a suitable boat and are pushed into a defined location in the retort. After that the furnace is closed and evacuated until a pressure lower than $9x10^{-5}$ mbar is achieved. During the heating the retort is still pumped so that the pressure due to temperature degassing does not increase over $2x10^{-4}$ mbar during the whole time. At 500°C the evacuation is stopped and argon (or another suitable gas mixture) is admitted into the retort with a pressure of approximately 800 mbar; then the heating is continued of a faster rate. When the braze ring melts (780°C) the gas is captured inside the cell and the heating is stopped.

The procedure needs a lot of experiences and has to be undertaken very carefully, so that the glass-to-metal joint remains undamaged and the brazed connection is sealed hermetically.

3 SKLEP

Energetski plinski odvodnik je pomemben element v prodajnem programu tovarne Iskra Zaščite. Da bi uvoz nadomestili z domačo celico, so bile sprožene razvojne dejavnosti, ki sta jih podprli tudi ministrstvi za znanost in za gospodarstvo.

V prispevku je na kratko opisano delovanje odvodnika ter konstrukcija z izdelavno tehnologijo. Pri tem so podrobneje predstavljeni trije manj običajni in dokaj zahtevni koraki v tehnološkem postopku, in sicer: problematika spoja steklo-kovina pri izdelavi vtalka, preverjanje tesnosti spojev in zaprtje plina v celico. V sedanjem stanju razvoja vlagamo največ naporov v odpravljanje netesnosti, v postavitev merilnih metod za testiranje električnih sposobnosti celice, v projekt skrajševanja postopka zaprtja (peči s posebnim grafitnim grelnikom) ter v razvoj oblikovno novih (večpolnih) in zato zmožnejših odvodnikov.

3 CONCLUSION

The power or so-called "heavy duty" gas arrester is an important product of Iskra Protections. In an attempt to substitute for imports by developing new types or domestic cell, several activities were started. The development is also supported by the Slovenian economy and science ministries.

The working principles, design and manufacturing technology of gas arresters are briefly treated in this paper. More detailed information is presented about the three basic steps of the manufacturing process: making glass-to-metal joints for the feedthrough, leak-detection of the arrester cells for checking the tightness and gas encapsulation by hard brazing. At the moment great efforts are being invested in leakage elimination, in the establishment of the testing procedures for controlling the cell's electrical performance, in shortening the encapsulation process (special furnaces with graphite heaters) and in the development of new shapes of gas arresters with more poles.

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