marine giuaSvili

piezoeleqtruli gardamsaxis diagnostireba magnitur-impulsuri danadgariT

წარდგენილია დოქტორის აკადემიური ხარისხის
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ჩვენ, ქვემორე ხელისმომწერნი ვადასტურებთ, რომ გავეცანით მარინე გიუაშვილის მიერ შესრულებულ სადისერტაციო ნაშრომს დასახელებით: ”პიეზოელექტრული გარდამსახის დიაგნოსტირება მაგნიტურ - იმპულსური დანადგარით” და ვაძლევთ რეკომენდაციას საქარველოს ტექნიკური უნივერსიტეტის ენერგეტიკისა და ტელეკომუნიკაციის ფაკულტეტის სადისერტაციო საბჭოში მის განხილვას დოქტორის აკადემიური ხარისხის მოსაპოვებლად.

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ავტორის ხელმოწერა

რეზიუმე

maRalsiCqaruli, intensiuri reJimebisTvis gankuTvnili teqnologiuri Tu diagnostikuri daniSnulebis danadgarebis gamokvlevisas masiurad gamoiyeneba sxvadasxva saxis maRalsixSiruli miniaturuli gamzomi gardamsaxebi, maT Soris piezoeleqtruli gamzomi gardamsaxebi, raTa Tavidan avicileoT gamzomi gardamsaxis bazis gaswvriv gasazomi signalis integrirebiT gamowveuli cdomilebebi. amave dros danadgarebis dinamkiuri gamocdebisas miRebuli informaciis srulfasovani damuSavebisaTvis aucilebelia gamoviyenoT gamzomi gardamsaxebis dinamikuri maxasiaTeblebis sruli paketi. rogorc wesi, miniaturuli gamzomi gardamsaxebi warmoadgens maRalsixSirul rxeviT sistemebs da maTi dinamikuri maxasiaTeblebis gansazRvra warmoadgens rTul teqnikur problemas. misi gadawyveta standartuli dartymiTi meqanikuri stendebiT (urnalebi) SeuZlebelia, vinaidan am dros ganviTarebuli impulsuri datvirTvis xangrZlivoba miliwamebis diapazonSia da gamzomi gardamsaxis xanmokle, mikrowamebis xangrZlivobis impulsebiT datvirTva SesaZlebelia mxolod uinercio (masis armqone) damrtymeli instrumentis gamoyenebiT.

milidan mikroteqnologiebze gadasvla SesaZlebeli gaxda afeTqebis talRis an impulsuri magnituri velis gamoyenebiT. maT Soris didi upiratesoba aqvs magnitur-impulsur teqnologias, romlis danergvas xeli Seuwyo Zlieri impulsuri magnituri velis generatorebis, didi sididis impulsuri denebisa da Zabvebis teqnikis ganviTarebam, mrewvelobis mier maRali Zabvis impulsuri kondensatorebisa da ganmmuxtvelebis aTvisebam.

diagnostikuri da teqnologiuri daniSnulebis nebismieri magnitur_impulsuri sistemis moqmedeba damyarebulia eleqtromagnituri velis eleqtrogamtar garemoSi gavrcelebisa da masze Zaluri zemoqmedebis movlenebze. impulsuri magnituri veli saSualebas iZleva ganaviTaros Zalze xanmokle mikrowamebis diapazonis Zaluri zemoqmedeba gamosacdel obieqtze. stu-Si aris sankt-peterburgis metrologiis institutis mier aRniSnuli masalebis gamoyenebiT Seqmnilia dartymiTi aCqarebis sazomi ПИ 93 seriis aCqarebis gardamsaxebis gamokvlevebis mdidari gamocdileba. disertaciaSi naCvenebia misi konstruqciuli sqema romelic Sedgeba korpusisagan 1, mgrZnobiare elementis 3 da wriuli an oTxkuTxa formis tvirTisagan 4 masiT m, gardamsaxi damagrebulia sakvlev obieqtze 2 weboTi an xraxniT. aseve naCvenebia obieqtis aCqarebis a(t) [gardamsaxisTvis aRgznebis] da gardamsaxis reaqciis v(t) oscilogramebi sxvadasxva SemTxvevisas. obieqtis moZraobis parametrebis dadgena xdeba Sesabamisi oscilogramis damuSuSavebiT.

dinamikuri gamocdebis dros miRebuli informaciis srulfasovani damuSavebisTvis aucilebelia gamoyenebuli gamzomi gardamsaxebis, maT Soris piezoeleqtruli gardamsaxis dinamikur

maxasiaTebelTa sruli speqtri, rac SeiZleba mopovebuli iqnes TviT gamzomi gardamsaxebis yovelmxrivi gamokvlevebiT maTze xanmokle dartymiTi zemoqmedebis saSualebiT, msgavsad eleqtruli wredebis sixSiruli maxasiaTeblebis kvlevisa impulsuri meTodiT.

dartymiTi piezoeleqtruli aCqarebis gamzomi gardamsaxebi warmoadgenen rxeviT sistemebs maRali sakuTari rxeviTi sixSireebiT. mowyobiloba SeiZleba modelirebuli iqnes erTi, ori an mravalmasian ganawilebul parametrebiani rxeviTi sistemebiT. maTi praqtikuli gamoyenebis dros gazomvis Sedegebis damuSavebisas, gazomvis maRali sizustis uzrunvelyofisaTvis saWiroa gvqondes informacia gamzomi gardamsaxebis amplitudur-sixSiruli maxasiaTeblebis Sesaxeb. es informacia SeiZleba mopovebul iqnes gardamsaxze aCqarebis xanmokle impulsis zemoqmedebiT, misi mgrZnobiarobis mimarTulebiT, gardamsaxis aRmgznebi impulsisa da Sesabamisi reaqciis registraciis da maTi Semdgomi damuSavebiT. cxadia, rom maRalsixSiruli gardamsaxis efeqturi aRgznebisaTvis saWiroa aRmgznebi impulsis xangrZlivoba naklebi an Tanazomadi iyos gardamsaxis sakuTari rxevebis periodTan SedarebiT.

dartymiTi aCqarebis gamzomi gardamsaxebis dinamikuri maxasiaTeblebis kvlevisas, gansakuTrebiT maTi arawrfivobis Seswavlisas saWiroa maTi aRgzneba impulsuri aCqarebiT, romlis pikuri mniSvneloba aris 10^3 -10^5 m/wm^2 xangrZlivobiT 10mkwm-i.

am TvalsazrisiT aqtualuria Seiqmnas gamzomi gardamsaxis dinamikuri maxasiaTeblebis gamosakvlevi mowyobiloba, romelic saSualebas mogvcems movaxdinoT sakvlevi obieqtis srulyofili diagnostika.

SemoTavazebuli magnitur-impulsuri diagnostikuri daniSnulebis danadgari Seicavs dammuxtav mowyobilobas, mcire induqciurobis mqone impulsuri kondensatorebis batareas, induqtors, romelSic moTavsebulia liTonis talRagamtari zed damagrebuli aCqarebis piezoeleqtruli gardamsaxi, komutators reversiulad CarTvadi dinistoris sqemiT. danadgari muSaobs Semdegnairad: komutatorze impulsis miwodebisas gaiReba dinistori da xdeba kondensatorebis batareis gadacla induqtorze. denis pirveli naxevartalRis gavlis Semdeg dinistori iketeba da aRar atarebs denis ukutalRas. induqtorSi moTavsebuli talRagamtari ganicdis impulsur meqanikur zemoqmedebas da masze damagrebuli sakvlevi obieqti aRigzneba erTjeradi unipolaruli impulsiT. impulsis xangrZlivoba stabiluria da ar aris damokidebuli gare faqtorebze. impulsuri zemoqmedebis sidide da xangrZlivoba damokidebulia mxolod damuxtvis Zabvis sidideze da ganmuxtvis wredis parametrebze.

naxevargamtaruli xelsawyoebiT didi simZlavreebis komutaciis dadebiTi gamocdileba arsebobs stu-Si. Cvens mier stu-Si damzadda magnitur-impulsuri sadiagnostiko danadgari, romelic Seicavs ТИ–3000 tipis sam mimdevribiT SeerTebul impulsur tiristorebs, rac 9 mgva simZlavris komutaciis saSualebas iZleva.

rogorc cnobilia, tiristorSi modebuli Zabvis blokireba xdeba ukuwanacvlebuli $p-n$ gadasvlis moculobiTi muxtis zoniT, romelic Zlieri eleqtruli velis moqmedebiT daclilia muxtis matareblebisgan da aqvs Zalian didi winaRoba. am zonis gamtarobis mkveTri gazrda da Sesabamisad tiristoris CarTva xdeba misi kargi gamtarobis mqone eleqtronul-xvreluri plazmiT Sevsebis gziT.

tiristorebis komutirebis dros xdeba didi winaRobis mqone zonis adgilas mdgradi mokle dengamtari plazmuri arxebis warmoqmna. tiristoris gadarTva inicirdeba Txeli bazis fenis gaswvriv emiter-bazis wredSi impulsuri denis gatarebiT. am fenis didi winaRobis gamo n^+-p gadasvlis mier eleqtronebis inJeqcia lokalizirebulia ramodenime aseuli mikronis siganis mqone viwro arxSi emiter-bazis sazRvris gaswvriv. tiristorSi am arxis sigane izrdeba, magram am procesis siCqare Zalzed dabalia da Seadgens $0.1 \div 0.05$ mm/mkwm. am movlenis gamo tradiciuli komutaciis mqone tiristorebSi praqtikulad SeuZlebelia didi farTis mqone dengamtari arxis Seqmna da didi simZlavreebis komutireba.

naxevargamtaruli komutatoris simZlavris mniSvnelovani zrda SesaZlebelia reversiulad CarTvadi dinistoris (rCd) saSualebiT, romelsac ara aqvs marTvis eleqtrodi. es ukanaskneli Canacvlebulia mmarTavi eleqtronul-xvreluri plazmuri feniT, romelic iqmneba koleqtoruli $p-n$ gadasvlis sibrtyeSi. es fena qmnis plazmur dengamtar arxs farTiT, romelic tolia xelsawyos siliciumis firfitis farTis.

rCd damzadebis procesSi xdeba ramodenime aTeuli aTasi paralelurad CarTuli erTimeores monacvle tiristoruli da tranzistoruli elementebis erToblioba. maTi damaxasiaTebeli zoma naklebia, vidre xelsawyos ganieri $n-$bazis sisqe. centraluri (koleqtoruli) gadasvla am elementebisTvis saerToa, maT saerTo aqvT marjvena n^+-p emiteruli gadasvlac. xelsawyoze modebulia muSa Zabva naCvenebi polarobiT. masze muSa Zabvis sawinaaRmdego polarobis ufro naklebi mniSvnelobis Zabvis modebiT (reversiT) elementebSi gadis marTvis denis impulsi da mas Tan sdevs plazmis inJeqcia $n-$zonaSi, romelic saerToa tranzistoruli da tiristoruli elementebisaTvis. koleqtorul gadasvlasTan tranzistorebisa da tiristorebis plazmuri svetebi erTmaneTs gadafaraven da warmoqmnian sakmaod erTgvarovan plazmur fenas. marTvis denis impulsis damTavrebisas xdeba rCd-is momWerebze nominaluri mimarTulebis muSa Zabvis modeba. am dros koleqtoruli gadasvlis plazmuri fenis eleqtronebi da xvrelebi wainacvleben n da p bazebSi Sesabamisad da xdeba xelsawyos CarTva mTel sibrtyeSi erTdroulad. vinaidan, xelsawyos marTva da muSaoba xorcieldeba erTi da igive momWerebis wyviliT, saWiroa Zalovani da marTvis wredebis gancalkeveba, rac SesaZlebelia gaJRenTvadi droselis gamoyenebiT. danadgari saSualebas iZleva movaxdinoT piezoeleqtruli aCqa-

rebis gamzomi gardamsaxebis testireba. disertaciaSi moyvanil diagnostikuri daniSnulebis magnitur-impulsur sistemebSi KPD – 25 – 170 tipis dinistoris gamoyeneba saSualebas iZleva danadgaris teqnologiur kvanZSi - induqtorSi 200kA denis gatarebas. rCd-is gamoyeneba msgavsad impulsuri tiristorebiT awyobili komutatorisa saSualebas iZleva induqtorSi gavataroT praqtikulad unipolaruli impulsuri deni, rac gansakuTrebiT mniSvnelovania piezoeleqtruli gamzomi gardamsaxebis diagnostirebis dros, rodesac gazomvebis sizuste didad aris damokidebuli sakvlev obieqtze Sesavali Zalovani zemoqmedebis xangrZlivobaze. gamosacdeli obieqtis metrologiuri maxasiaTeblebi _ struqtura, sakuTari rxevebis sixSire, demfirebis koeficienti, mgrZnobiaroba, arawrfivoba ganisazRvreba mowyobilobis reaqciisa da impulsuri zemoqmedebis speqtralur simkvriveTa fardobiT. es fardoba martivdeba, rodesac impulsuri zemoqmedeba Zalze xanmoklea da uaxlovdeba delta funqcias, rac niSnavs, rom gamosacdeli obieqtis gadacemis funqciisa da reaqciis speqtraluri simkvriveebi praqtikulad Tanxvdenili funqciebia. am dros obieqtis reaqciis speqtraluri simkvrive praqtikulad igivea, rac obieqtis kompleqsuri sixSiruli maxasiaTebeli da obieqtis diagnostikuri kvleva midis mis impulsur zemoqmedebaze reaqciis analizTan.

sadiagnostiko obieqtis, piezoeleqtruli gamzomi gardamsaxis Zalzed xanmokle impulsur aRgznebaze reaqciis speqtraluri simkvrivis analiziT SesaZlebelia garadamsaxis struqturis dadgena, amplitudur – sixSiruli, sakuTari sixSireebis, demfirebis, arawrfivobis da sxva metrologiuri maxasiaTeblebis maRali sizustiT gansazRvra.

amgvarad, SemoTavazebul danadgarSi rCd-s komutatorad gamoyeneba komutirebuli simZlavris zrdasTan erTad saSualebas gvaZlevs gavaumjobesoT danadgaris metrologiuri maxasiaTeblebi.

Abstract

At studying diagnostic or technological facilities intended for intensive modes, various high frequency tiny measuring transformers, including piezoelectric measuring ones, are used to avoid errors caused by integration of signals to be measured lengthwise to measuring transformer base. In the same time, at facilities dynamic testing, for complete processing of received information, it is necessary to use complete package of dynamic patterns of measuring transformers. As a rule, tiny measuring transformers represent high frequency oscillatory systems. Determination of their dynamic patterns is a heavy technical problem. It is impossible to solve this problem with standard impact mechanical beds because the duration of impulse load developed at that moment is in the range of milliseconds and transformer loading with short impulses of msec. duration is possible only by using impact instrument (un-weighed) without inertia.

Transition to microfabrication technologies by using impulsive magnetic field became possible. The most preferable among them is magnetic-impulsive technology, its implementation was supported by the development of strong impulsive field generators, techniques of high make-and-break currents and voltages, adoption of high voltage impulsive condensers and dischargers in manufacturing industry.

Activity of any magnetic-impulsive system of diagnostic and technological intention is based on the spreading of electromagnetic field through conductivity environment and the events of power influence on it. Impulsive magnetic field allows to develop power influence (of the shortest msec. range) on subject of research. In STU there is an experience of researching impact acceleration transformers of PI-93 series made by using mentioned materials by St. Petersburg metrologty institute. Its structural scheme is shown in the thesis work. It consists of body 1, detector 3 and round or quadrangular load 4 with the mass m, the transformer is fixed on subject of research with two adhesives or screws. Object acceleration a(t) [excitation for transformer] and transformer reaction v(t) oscillograms in various cases are shown as well. Object movement parameters are determined by working out corresponding oscillograms.

For complete processing of the information received after dynamic tests full spectrum of dynamic data of used measuring transformers, including piezoelectric transformers, which can be received by comprehensive testing of measuring transformers by means of short impact influence similar to the study of frequency data by impulsive method.

Transformers measuring impact piezoelectric acceleration represent oscillation systems with high oscillation frequencies. A facility can be modeled by two or multimass oscillation systems with redistributed parameters. When using them in practice, during the processing of measurement results, for provision of high accuracy it is necessary to have information on amplitude-frequency data of transformers. This information can be found by influence of acceleration short impulse on transformers, in its sensitivity direction, by registration of transformers excitation impulse and corresponding reactions and subsequent processing of them. It is obvious that for effective excitation of high frequency transformers, duration of excitation impulse has to be less than or uniform to natural oscillation period of transformer.

At researching dynamic data of transformers measuring impact acceleration, especially when studying their nonlinearity, it is necessary to excite them with impulsive acceleration peak value of which is 10^3-10^5 m/sec^2 with duration of 10 msec.

In this purpose it is urgent to make facility for studying dynamic data of measuring transformers which allows preparing complete diagnostic of research object.

Suggested facility of magnetic-impulsive diagnostic intention contains a charging arrangement, a battery of impulsive condensers having low induction, an induc-

tor in which there is a metal wave conductor with fixed piezoelectric transformer on it, circuit changer with diode-thyristor scheme being switched reversibly. The facility works as follows: when passing impulse to the circuit changer the diode-thyristor opens and condenser battery is discharged on inductor. After passing current first half-wave diode-thyristor is closed and it does not conduct current back wave. Wave-conductor inside inductor is affected by impulsive mechanic influence and research object fixed on it is excited by single-stage unipolar impulse. Impulse duration is stable and does not depend on external factors. Magnitude and duration of impulsive influence depend only on the value of charging voltage and parameters of discharging circuit.

STU has positive experience of power commutation by semiconductor facilities. We have made magnetic-impulsive diagnostic arrangement in STU. It contains TI-3000 type 3 impulsive series connected diode-thyristors which makes possible 9 MW commutation.

As it is known, voltage blocking in entire diode-thyristor is done by the zone of volumetric charge of set-back p-n transition, which is discharged of charge bearers by the activity of strong electric field and has high resistance. Abrupt increase in conductivity of this zone and diode-thyristor corresponding switching is done by filling it with electronic-orifice plasma of high conductivity.

During commutation of diode-thyristor, steady current conductive plasma channels are formed instead of high resistance zone. Switching diode-thyristor is initiated alongside thin base layer in emitter-base circuit by conducting impulsive current. Due to high resistance of this layer injection by n^+ -p transition is localized in the narrow channel of several hundred microns width alongside emitter-base border. The width of this diode-thyristor increases but the speed of this process is too low and consists 0.1÷0.05 mm/msec. Due to this phenomenon in traditional commutation diode-thyristors making large area current-carrying channels and commutation of high powers are impossible.

Significant increase in the power of semiconductor current changer is possible by means of reversibly switching diode-thyristor which does not have operating electrode. The last one is replaced by operating electronic-orifice plasma layer made in the plane of collector p-n transition. This layer makes plasma current-carrying channel with the area equal to facility silicon plate area.

During the process of making dinistor, several thousands in-parallel alternate thyristor and transitory parts are united. Their characterizing size is less than the thickness of facility wide n-base. Central (collector) transition for these parts is common, they have common right n^+-p emitter transition. Operating voltage is spread on the facility with shown polarity. By spreading (reversion) less voltage than polarity resistant to operating voltage, operating current impulse is passing in parts and it is accompanied with plasma injection in n-zone common for transistor and thyristor parts. At collector transition plasma columns of transistors and thyristors will overlap each other and make quite homogeneous plasma layer. At finishing operating current impulse, spreading of nominal direction operating voltage is done. At that moment electrons and orifices of collector transition plasma layer will move to n and p bases respectively and the facility is switched in entire plane simultaneously. Due to the fact that regulation and operation of the facility is done by the same pair of binders, separation of power and operating circuits is needed. It is possible by means of using permeable orifice choke. The facility makes possible testing of transformers measuring piezoelectric acceleration. Using KPD-25-170 type dinisters in magnetic-impulsive systems lets conduct 200 kA current through facility technological node. Using diode-thyristor, similar to circuit changers constructed by impulsive tests, lets conduct prac-

tically unipolar impulsive current through inductor. This is especially important when diagnosing piezoelectric measuring transformers when accuracy of measurements greatly depends on research object, duration of introductory power influence. Metrologic properties of research object – structure, demphing coefficient, frequency of natural oscillation, sensitivity, noninearity are determined by the ratio of spectral densities of impulsive influence and facility reaction. This ratio becomes simple when impulse influence is quite short and comes up to delta value i.e. spectral densities of research object transition function and reaction are practically coincided functions. At this moment spectral density of object reaction is practically equal to its complex frequency pattern and its diagnostic research to impulse influence of reaction analysis.

By spectral analysis of density of the reaction to quite short impulsive excitation of piezoelectric measuring transformer, determination of transformer structure, amplitude-frequency, natural frequencies, demphin, nonlinearity and determination of other metrologic properties are possible.

Thus, use of diode-thyristor in the suggested facility as a current changer together with increasing commutated power lets develop metrologic properties of the facility.

შინაარსი

ცხრილების ნუსხა

ნახაზების ნუსხა

შესავალი

samuSaos aqtualoba. mecnierebisa da teqnikis ganviTarebis Tanamedrove etapze mniSvnelovani Sedegebia miRweuli mZlavr impulsur energetikaSi, impulsuri energetikuli teqnologiebis gamoyenebis sferoSi, rogorc samxedro, aseve mSvidobiani miznebisaTvis. gansakuTrebiT efeqturia iseTi impulsuri teqnologiebis gamoyeneba, rogoricaa:

- liTonebis magnitur-impulsuri meTodebiT damuSaveba; konstruqciuli masalebisa da nakeTobebis dinamikuri gamocda;
- meqanikuri dartymis parametrebis sazomi piezoeleqtruli gardamsaxis diagnostireba;

aRniSnul teqnologiebs Soris gansakuTrebiT unda aRiniSnos liTonebis damuSaveba Zlieri impulsuri magnituri veliT, rodesac xorcieldeba teqnologiuri operaciebi: moWera, gaSla, datvifrva, SeduReba, diagnostireba da sxva [2].

maRalsiCqaruli, intensiuri datvirTvebisTvis gankuTvnili teqnologiuri Tu diagnostikuri daniSnulebis danadgarebis gamokvlevisas, imis gamo rom meqanikur Zabvebs, deformaciebs, aCqarebebs xSirad aqvT talRuri xasiaTi, masiurad gamoiyeneba sxvadasxva saxis maRalsixSiruli miniaturuli gamzomi gardamsaxebi, maT Soris piezoeleqtruli gamzomi gardamsaxebi, raTa Tavidan avicileT gamzomi gardamsaxis bazis gaswvriv gasazomi signalis integrirebiT gamowveuli cdomilebebi. amave dros danadgarebis dinamkiuri gamocdebisas miRebuli informaciis srulfasovani damuSavebisaTvis aucilebelia gamoviyenoT gamzomi gardamsaxebis dinamikuri maxasiaTeblebis sruli paketi. rogorc wesi, miniaturuli gamzomi gardamsaxebi warmoadgens maRalsixSirul rxeviT sistemebs da maTi dinamikuri maxasiaTeblebis gansazRvra warmoadgens rTul teqnikur problemas. misi gadawyveta standartuli dartymiTi meqanikuri stendebiT (urnalebiT) SeuZlebelia, vinaidan am dros ganviTarebuli impulsuri datvirTvis xangrZlivoba miliwamebis diapazonSia da gamzomi

gardamsaxis xanmokle, mikrowamebis xangrZlivobis impulsebiT datvirTva SesaZlebelia mxolod uinercio (masis armqone) damrtymeli instrumentis gamoyenebiT [1,3].

milidan mikroteqnologiebze gadasvla SesaZlebeli gaxda afeTqebis talRis an impulsuri magnituri velis gamoyenebiT. maT Soris didi upiratesoba aqvs magnitur-impulsur teqnologias, romlis danergvas xeli Seuwyo Zlieri impulsuri magnituri velis generatorebis, didi sididis impulsuri denebisa da Zabvebis teqnikis ganviTarebam, mrewvelobis mier maRali Zabvis impulsuri kondensatorebisa da ganmmuxtvelebis aTvisebam.

diagnostikuri da teqnologiuri daniSnulebis nebismieri magnitur-impulsuri sistemis moqmedeba damyarebulia eleqtromagnituri velis eleqtrogamtar garemoSi gavrcelebisa da masze Zaluri zemoqmedebis movlenebze. impulsuri magnituri veli saSualebas iZleva ganaviTaros Zalze xanmokle mikrowamebis diapazonis Zaluri zemoqmedeba gamosacdel obieqtze [4].

sxvadasxva saxis masalebis an namzadebis dinamikuri maxasiaTeblebis gansazRvrisaTvis saWiroa, rom cilindruli formis liTonis ReroSi, romelic meqanikuri talRagamtaris rols asrulebs, aRiZvras mikrowamebis diapazonis xangrZlivobis meqanikuri Zabvebi, deformaciebi da aCqarebebi. amave dros standartuli, meqanikur dartymaze gamosacdeli stendebi (meqanikuri qanqariani an sxva tipis urnalebi) saSualebas iZleva ganaviTaron miliwamebis diapazonis impulsuri datvirTebi. arsebul meqanikur dartymaze gamosacdel stendebSi gamoyenebulia ori myari sxeulis garkveuli siCqariT dajaxebis efeqti, romlis drosac dartymaSi monawile sxeulebis kinetikuri energia nawilobriv gadadis am sxeulebis impulsuri deformaciis energiaSi. sxeulebSi warmoSobili impulsuri deformaciebis xangrZlivoba da intensiuroba damokidebulia dartymis siCqareze, dartymaSi monawile sxeulebis masaze, masalaze, sixisteze, geometriul zomebsa da konfiguraciaze. amis gamo, meqanikur dartymiT stendebSi (urnalebi) xanmokle impulsebis miReba SezRudulia da

Semoifargleba miliwamebis diapazoniT, mikrowamebis diapazonze gadasvla maTi saSualebiT principulad SeuZlebelia [6].

samuSaos mizania ufro xanmokle impulsuri deformaciebi da meqanikuri Zabvebi aRiZvras myar sxeulebSi maTi datvirTviT „umaso" damkvrelis _ impulsuri magnituri velis saSualebiT. am dros impulsuri zemoqmedebis xangrZlivoba mikrowamebis diapazonisaa da miiRweva deformaciis didi siCqareebi, rac saSualebas iZleva davadginoT gamosakvlevi masalebis dinamiuri maxasiaTeblebi (dinamiuri denadobisa da simtkicis zRvrebi). aseve myar sxeulSi_meqanikur talRagamtarSi mikrowamebis diapazonis impulsuri deformaciis warmoSobisas talRagamtaris torcebi asruleben moZraobas maRali donis impulsuri aCqarebebiT, rac saSualebas iZleva torcze damagrebuli namzadi (gamzomi gardamsaxi, naxevargamtariani diodi, tranzistori, mikrosqema da sxva) gamokvleul iqnes dartymamedegobasa da dartymamdgradobaze.

rogorc avRniSneT, milidan mikroteqnologiebze gadasvla SesaZlebelia uinercio damkvrelis gamoyenebiT, romlis roli SeiZleba Seasrulos detonaciurma talRam an impulsurma magniturma velma. dReisaTvis impulsuri magnituri veli gamoiyeneba rogorc puansoni an matrica Txelkedliani kargi eleqtrogamtarobis mqone masalisagan damzadebuli detalebis tvifvris, mownexvis, gaSlis, kalibrebis da sxva teqnologiuri operaciebis Sesasrulelad. igi warmatebiT cvlis detonaciur teqnologias, rodesac afeTqebis talRa asrulebs puansonis an matricis rols. am ukanasknels aqvs didi upiratesoba praqtikuli gamoyenebis TvalsazrisiT [7,5].

ZiriTadi amocanebi:

1. Sesabamisad, intensiuri datvirTvebisTvis gankuTvnili diagnostikuri, teqnologiuri, satransporto Tu energetikuli daniSnulebis danadgarebi eqspluataciaSi Seyvanamde saWiroa gamoicados dinamikur dartymiT datvirTvebze, rac SesaZlebelia

gamosacdeli mowyobilobebiT, romelTa ZiriTad nawils Seadgens didi sididis impulsuri denis generatorebi [10].

2. magnitur-impulsuri diagnostikuri danadgarebis moqmedeba emyareba impulsuri magnituri velis eleqtrogamtar sxeulze Zalovan zemoqmedebas, rodesac vlindeba zedapirisa da siaxlovis efeqtebi.

3. damuSavebulia aCqarebis gamzomi gardamsaxebis Tavisufali rxevebis oscilogramirebis meTodika da gardamsaxis amplitudur-sixSiruli maxasiaTeblis ageba, rac iZleva srul informacias gardamsaxis struqturis da sakuTari sixSireebis Sesaxeb [23].

kvlevis meTodebi.

sadisertacio samuSaos Sesrulebisas Cvens mier stu-Si damuSavebulia magnitur-impulsuri sistema, romlis impulsuri denis generatorSi gamoyenebulia ИРТ-2 tipis ignitronuli ganmmuxtveli. misi nominaluri Zabva da deni Sesabamisad aris 10kv da 100ka, magram mas ara aqvs ventiluri Tviseba, ris gamoc denis generatori Sesrulda denis watacebis sqemiT damatebiTi ganmmuxtavis gamoyenebiT. sistemaSi gadawyvetilia ZiriTadi da damatebiTi ganmmuxtvelebis anTebis da eleqtronuli oscilografebis gaSvebis procesebis sinqronizaciis amocana. aqac, sistemis sainformacio-sazomi kompleqsi Seicavs impulsuri denebis, deformaciebisa da aCqarebebis gamzom gardamsaxebs, optikur-eleqtronul gardamqmnels an analogur-cifrul gardamqmnels informaciis damuSavebis Sesabamisi sistemiT [19,56].

samecniero siaxle.

1. damuSavebulia cilindruli Reros gverdidan aRgzneba impulsuri magnituri velis saSualebiT, Sedegad, impulsuri deformaciis aRgznebis adgili ReroSi maqsimalurad iqna miaxlovebuli talRagamtaris muSa torecTan, ris gamoc minimumamde dayvaneba dispersiuli movleniT gamowveuli damaxinjebebi. am ideis realizeba SesaZlebelia magnitur-impulsuri diagnostikuri daniSnulebis danadgarSi, romlis pirdapiri daniSnulebaa

piezoeleqtruli dartymiTi aCqarebis gamzomi gardamsaxis sakuTari sixSireebis gansazRvra [57].

2. aCqarebis gamzomi gardamsaxebis Tavisufali rxevebis oscilogramirebis damuSavebis meTodika da gardamsaxis amplitudur-sixSiruli maxasiaTeblis speqtruli meTodiT gansazRvra, rac iZleva srul informacias gardamsaxis struqturis da sakuTari sixSireebis Sesaxeb [58,59].

3. diagnostikuri daniSnulebis magnitur-impulsuri danadgari, sadac komutatoris rols asrulebs reversiulad CarTvadi dinistori, romelic gamoirCeva xanmedegobiT, muSaobis stabilurobiT da iZleva unipoaruli impulsuri denis miRebis saSualebas.

praqtikuli Rirebuleba.

warmodgnili meTodika saSualebas iZleva magnitur-impulsuri diagnostikuri danadgaris teqnologiur kvanZSi _ induqtorSi miviRoT Zalzed xanmokle da mZlavri impulsi, Tu danadgarSi komutatorad gamoviyenebT reversiulad CarTvad dinistors. rCd ramodenime aseuli kiloamperi denis komutirebis saSualebas iZleva erTeul mikrowamebSi.

naxevargamtaruli xelsawyoebiT komutaciis dadebiTi gamocdileba arsebobs stu-Si. Cvens mier damzadda magnitur-impulsuri sadiagnostiko danadgari, romelic Seicavs ТИ–3000 tipis oTx mimdevrobiT SeerTebul impulsur tiristorebs, rac 9mgva simZlavris komutaciis saSualebas iZleva. tradiciuli komutaciis mqone tiristorebSi praqtikulad SeuZlebelia didi farTis mqone dengamtari arxis Seqmna da didi simZlavreebis komutireba [20,19].

naxevargamtaruli komutatoris simZlavris mniSvnelovani zrda SesaZlebelia reversiulad CarTvadi dinistoris (rCd) saSualebiT, romelsac ara aqvs marTvis eleqtrodi. es ukanaskneli Canacvlebulia mmarTavi eleqtronul-xvreluri plazmuri feniT, romelic iqneba koleqtoruli p–n gadasvlis sibrtyeSi. es fena

qmnis plazmur dengamtar arxs farTiT, romelic tolia xelsawyos siliciumis firfitis farTis.

reversiulad CarTvadi dinistorebis gamoyeneba msgavsad impulsuri tiristorebiT awyobili komutatorisa saSualebas iZleva induqtorSi gavataroT praqtikulad unipolaruli impulsuri deni, rac gansakuTrebiT mniSvnelovania piezoeleqtruli gamzomi gardamsaxebis diagnostirebis dros, rodesac gazomvebis sizuste didad aris damokidebuli sakvlev obieqtSi Semavali Zalovani zemoqmedebis xangrZlivobaze. danadgarSi reversiulad CarTvadi dinistoris kondensatoris ganmmuxtavad gamoyeneba komutirebuli simZlavris zrdasTan erTad saSualebas iZleva gaumjobesdes sadiagnostiko danadgaris metrologiuri maxasiaTeblebi [17,32].

sadisertacio samuSaos ZiriTadi Sedegebi moxsenebulia stu-s studentTa Ria saerTaSoriso samecniero konferenciebze. **publikaciebi.** sadisertacio samuSaoebis Sedegebi gamoqveynebuli iqna oTx samecniero statiaSi. miRebuli maqvs saqarTvelos ori patenti (PP 5374 da PP4350).

Ddisertaciis struqtura da moculoba. Ddisertacia Sedgeba Sesavalisa da sami Tavisagan, romlebic gadmocemulia 101 gverdze. Seicavs 35 naxazs, 3 cxrils da 73 dasaxelebis literaturas.

1. ლიტერატურის მიმოხილვა

Tavi I. teqnikuri mowyobilobebis diagnostika

1.1 eleqtruli mowyobilobebis diagnostikis zogadi sakiTxebi.

mecnierebisa da teqnikis ganviTarebis Tanamedrove etapze mniSvnelovani Sedegebia miRweuli mZlavr impulsur energetikaSi, impulsuri energetikuli teqnologiebis gamoyenebis sferoSi, rogorc samxedro, aseve mSvidobiani miznebisaTvis. gansakuTrebiT efeqturia iseTi impulsuri teqnologiebis gamoyeneba, rogoricaa:

- liTonebis magnitur-impulsuri meTodebiT damuSaveba; konstruqciuli masalebisa da nakeTobebis dinamikuri gamocda;
- meqanikuri dartymis parametrebis gamzomi piezoeleqtruli gardamsaxis diagnostireba;

aRniSnul teqnologiebs Soris gansakuTrebiT unda aRiniSnos liTonebis damuSaveba Zlieri impulsuri magnituri veliT, rodesac xorcieldeba teqnologiuri operaciebi: moWera, gaSla, datvifrva, SeduReba, diagnostireba da sxva.

eleqtromowyobilobis teqnikuri diagnostika SedarebiT axali mecnierebaa. teqnikuri diagnostika momdinareobs terminidan diagnozi rac niSnavs Secnobas, gansazRvras. eleqtruli mowyobilobis diagnostikis amocanaa obieqtis parametrebisa da struqturis dadgena, mowyobilobis gamarTva, muSaobis unarisa da swori funqcionirebis Semowmeba, defeqtebis moZieba. diagnostika, rogorc procesi, xorcieldeba diagnostirebis raime saSualebebiT, romlebic SeigrZnoben da analizs ukeTeben obieqtis reaqcias SesaZlo zemoqmedebaze da diagnostirebis Sedegs _ diagnozs.

eleqtruli mowyobilobebis gaumarTaobas da mtyunebas, agreTve mowyobilobaTa mdgomareobis damaxasiaTebeli parametrebis gauaresebas, iwvevs ZiriTadad gare fizikuri faqtorebi:

- obieqtis Siga da garemos temperaturis cvlileba;
- sinestis arseboba;

- agresiuli garemo (gazebi, siTxeebi, orTqli, mtveri, mwerebi);
- dartymisa da vibraciis gavlena.

rogorc cnobilia, temperaturis cvlilebis Sedegad icvleba obieqtis calkeuli detalebis geometriuli zomebi, vinaidan liTonebisTvis wrfivi gafarToebis koeficienti sakmaod mniSvnelovania, amis gamo impulsuri denis generatorSi adgili aqvs kondensatorebis, komutatorsa da induqtoris SemaerTebel sadenebis meqanikur deformaciebs, eleqtruli kontaqtebis xarisxis cvlilebas, damiwebis winaRobis gazrdas da sxva. garda eleqtruli winaRobisa, temperaturis cvlilebas iwvevs eleqtrul mowyobilobebSi gamoyenebuli masalebis sxva Tvisebebis cvlilebac, kerZod, dieleqtrikuli da magnituri SeRwevadobebis Secvla. temperaturis zrdasTan erTad, nawilobriv iSleba zogierTi eleqtro saizolacio masala, xdeba misi dabereba, romelsac xels uwyobs maionizirebeli gamosxiveba, eleqtruli da magnituri velebis zemoqmedeba, vibracia, dartymiTi zemoqmedeba da sxva [16].

aRniSnuli faqtorebi eleqtrul mowyobilobebSi amcirebs sakomutacio kvanZebis (eleqtrul kontaqtebis) saimedoobas, koroziuli procesebi, romelTa identificireba xdeba agresiuli garemos zemoqmedebiT. sinestis gamo uaresdeba eleqtrul kontaqtebSi eleqtrogamtaroba. eleqtruli kontaqtebi ifareba Jangis feniT, izrdeba koroziis liTonis siRrmeSi gavrcelebis siCqare. aseve eleqtrosaizolacio detalebis zedapirSi arsebuli mikrobzarebi sinestis arsebobis pirobebSi ivseba siTxiT. gayinvis dros, dabali temperaturis pirobebSi, es bzarebi farTovdeba da Zlierdeba arsebuli defeqti.

dabereba da cveTa aris TandaTanobiTi Seuqcevadi procesebi, romlebic mkveTrad auareseben eleqtrul mowyobilobebis elementebis parametrebs. daberebis procesi mimdinareobs uwyvetad, imisdamiuxedavad, obieqti imyofeba muSa mdgomareobaSi Tu ara, maSin, cveTis procesi dakavSirebulia mowyobilobis

funqcionirebasTan. impulsur generatorSi masalebis cveTa da dabereba aris bunebrivi procesebi, romelTa Tavidan acileba SeuZlebelia, da SeiZleba mxolod nawilobriv SevasustoT maTi moqmedebis Sedegi.

eleqtruli mowyobiloba warmoadgens rTul teqnikur sistemas, romlis muSaobis saimedooba SeiZleba uzrunvelyofil iqnas aparaturuli da informaciuli RonisZiebebiT, mimarTuli defeqtebis gamovlenisa da gamosworebisken.

teqnikuri sistemis diagnostikuri uzrunvelyofa iwyeba sistemis proeqtirebisas, grZeldeba misi damzadebisas da Semdgom eqspluataciisas, masalebisa da teqnologiebis SerCeviT, saeqspluatacio pirobebis SemuSavebiT da maTi dacviT.

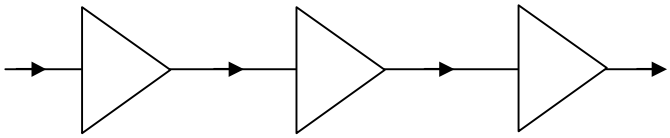
obieqtis mdgomareobis Semowmeba xdeba testuri da funqcionaluri diagnostikiT. testuri diagnostika moicavs Sesavali zemoqmedebebis erTobliobas da Tanmimdevrobas, romlis drosac obieqtis reaqciis analizi saSualebas iZleva dadgindes obieqtis teqnikuri mdgomareoba. obieqtis funqcionaluri diagnostika xorcieldeba rogorc uwyvetad, aseve periodulad, an epizodurad specialuri algoriTmis mixedviT, risTvisac saWiroa obieqtis da misi gaumarTaobebis maTematikuri modelebi. rogorc wesi, maTematikuri modeli aris diferencialuri da algoriTmuli gantolebebi, empiriuli formulebi, cxrilebi, grafikebi, romlebic aRweren obieqtis an mis calkeul elementebSi mimdinare procesebs.

saSualebebs, romlebiTac dadgindeba obieqtis teqnikuri mdgomareoba ewodeba diagnostirebis teqnikuri saSualebebi. eseni SeiZleba iyos aparaturuli an programuli, Sinagani an garegani, avtomatizirebuli, specializirebuli an universaluri da sxva. operatori an gamwyobi aseve SeiZleba ganxilul iqnes, rogorc diagnostirebis saSualeba.

diagnostirebis dros, operatori gamoavlens ra obieqtis gaumarTaobis niSnebs, adgens misi funqcionirebis siswores da gansazRvravs gaumarTavi kvanZis Ziebis meTodikas. amisaTvis,

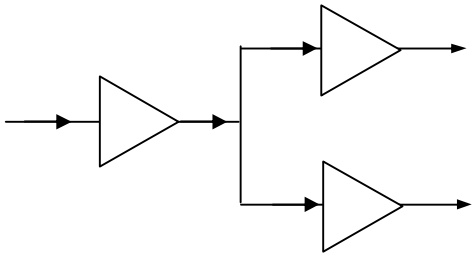
obieqtis sadiagnostiko signali SeiZleba mimarTul iqnes mimdevrobiT, ganStoebul an gadarTvad wredebSi [15].

mimdevrobiTi wredi Seicavs obieqtis Semadgenel elementebs ise, rom erTi elementidan gamosavali warmoadgens Semdegi elementis Sesavals. amis Sedegad sadiagnostiko signali gadis elementebSi mimdevrobiT ukukavSirisa da ganStoebebis gareSe.



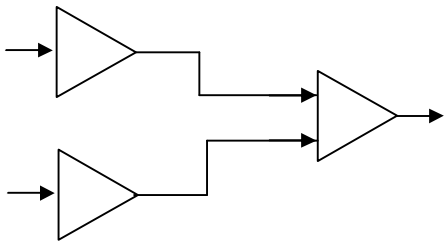
nax. 1.1

ganStoebuli wredi SeiZleba iyos orgvari: ganSladi (nax.1.2)



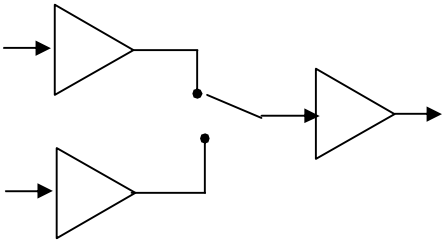
nax. 1.2

an krebadi (nax. 1.3)



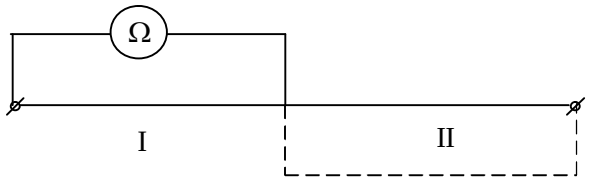
nax. 1.3

gadarTvadi wredi (nax. 1.4) Seicavs komutators, romlis saSualebiT mocemul situaciaSi warmoiSveba signalis Sesabamisi wredis konfiguracia.



nax. 1.4

mimdevrobiT wredSi diagnostirebis procesi SeiZleba mniSvnelovnad daCqardes Suaze gayofis meTodis gamoyenebiT (nax. 1.5)



nax. 1.5

amisaTvis, mimdevrobiT SeerTebuli elementebis gamosavalSi araswori signalis arsebobisas mimdevrobiTi wredi iyofa Suaze. wredis pirveli naxevris gamosavalSi swori signalis arsebobisas dazianebuli elementi iZebneba wredis meore naxevarSi.

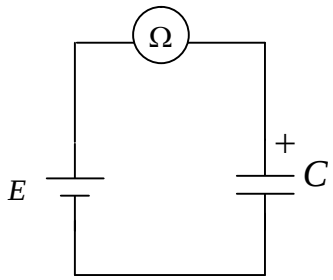
arsebobs gaumarTvi elementebis aRmoCenis sxva meTodebic: mkvebavi Zabvis Semowmeba, meTodi `bolodan sawyisisken~, blokebis Secvlis meTodi, gamoricxvis meTodi da sxva.

1.2. Zlieri impulsuri denis generatoris diagnostika

Zlieri impulsuri denis generatori warmoadgens eleqtronul mowyobilobas, romelic Seicavs rezistorebs, kondensatorebs, induqtorebs da naxevargamtarul xelsawyoebs.

rezistorebSi yvelaze farTod gavrcelebuli gaumarTaobaa dengamtari rezistoruli fenis dazianeba (dawva), rezistorSi gamavali dauSvebeli denis gamo. am dros rezistorSi Cndeba wyveta an mokled CarTva gamdnari masalis mier warmoqmnili zRudariT. Sesabamisad, rezistoris parametri _ winaRoba Secvlilia. generatoris maRali Zabvis wredSi SesaZlebelia rezistoruli fenis dazianeba TvaliT SeumCneveli garegnuli niSnebiT, rac aris mizezi rezistoris winaRobis mniSvnelovani cvlilebisa misi gadidebis an Semcirebis mimarTulebiT.

kondensatorebSi yvelaze farTod gavrcelebuli dazianebaa mokled CarTva, rac SeiZleba aRmovaCinoT maRalwinaRobiani ommetriT. amisaTvis ommetri yvelaze maRali winaRobis gazomvis diapazoniT unda mivuerTod kondensatoris momWerebs.



nax. 1.6

Tu kondensatori eleqtrolituria unda davicvaT CarTvis polaroba. kondensatoris gasazomi winaRoba TandaTan unda gaizardos Zalze did mniSvnelobamde da Semdeg darCes mudmivi. kondesatoris tevadoba mowmdeba specialuri LC xelawyoTi.

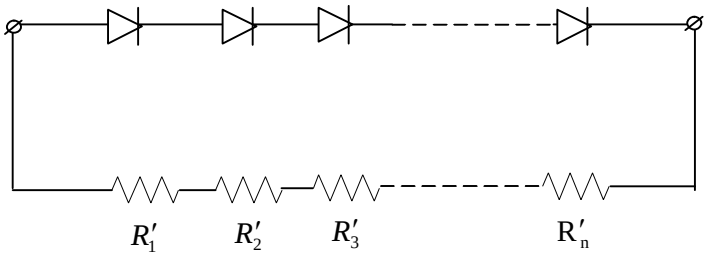
1.3. tiristorebisa da dinistorebis diagnostireba damzadebisa da eqspluataciis stadiaze.

am xelsawyoTa praqtikuli gamoyenebisas xSirad maTi klasi (muSa Zabva V) gansxvavebulia (naklebia) im mowyobilobis nominalur ZabvasTan V_σ SedarebiT, sadac unda iyvnen gamoyenebuli. amitom saWiroa maTi wyobilis damuSaveba, sadac n raodenobis xelsawyo mimdevrobiT aris SeerTebuli.

$$n = \frac{V_\sigma}{V_{\sigma k}}$$

magaliTad, piezoeleqtruli aCqarebis gamzomi gardamsaxis dinamiuri maxasiaTeblebis ganmsazRvrel magnitur _ impulsur danadgarSi K16–05, impulsuri denis generatorSi gamoyenebulia tiristoruli komutatori, romelic awyobilia sami mimdevrobiT SeerTebuli me-9 klasis impulsuri tiristorebisagan TU–3000, romlis muSa Zabvaa 900v, denis maqsimaluri mniSvneloba (dartymis deni) _ 10ka. am xelsawyoTa winaRoba (gaJonvis denis mimarT) xasiaTdeba didi ganbneviT. amitom xelsawyoTa SerCevisas winaRobis mixedviT sakmaod didi partiidanac ki ver uzrunvelyofs statikuri Zabvis Tanabar ganawilebas xelsawyoTa Soris da maT Soris sxvaoba SeiZleba aRwevdes xelsawyos nominaluri Zabvis 50%-s. diodebis magaliTze saWiroa Zabvis

gamaTanabrebeli Stos Seqmna maRalvoltiani rezistorebis gamoyenebiT, romlis parametrebi irCeva pirobidan (1.1), (nax. 1.7).



nax. 1.7

$$\frac{R_1^{'} \cdot R_1}{R_1^{'} + R_1} = \frac{R_2 \cdot R_2^{'}}{R_2 + R_2^{'}} = \frac{R_3 \cdot R_3^{'}}{R_3 + R_3^{'}} = \cdots = \frac{R_n \cdot R_n^{'}}{R_n + R_n^{'}} \qquad (1.1)$$

sadac $R_1, R_2, R_3 \ldots R_n$ diodebis ukuwinaRobebia, $R_1^{'}, R_2^{'}, R_3^{'} \ldots R_n^{'}$ – rezistoris winaRobebia [15].

(1.1) pirobis dakmayofileba saWiroa, rogorc mowyobilobis damzadebis stadiaze, aseve misi eqspluataciis periodSi, rodesac mimdinareobs izolaciis cveTisa da daberebis intensiuri procesi da xelsawyos rigis periodduli diagnostireba. damatebiTi rezistoris SerCevisas praqtikulad $\frac{R}{R^{'}} = 5 \div 10$.

1.4. ganmmuxtavebis zogadi mimoxilva

1.4.1. ganmmuxtavebis saxeebi da maT mimarT wayenebuli moTxovnebi

cnobilia, Semdegi saxis ganmmuxtavebi: vakuumuri, ionuri, lazeruli da myar dieleqtrikiani. ganmmuxtavebis Tvisebebi arsebiTad aris damokidebuli, ara marto maT tipebze, aramed generatoris impulsuri denebis muSa parametrebze, aseve generatoris konstruqciaze, izolaciisa da eleqtrodebis masalaze, inicirebis xerxebze da a.S. ganmmuxtavebi unda akmayofilebdnen Semdeg ZiriTad moTxovnebs:

1) unda ayovnebdnen garRvevebs da gadafarvis muSa Zabvas. ganmmuxtavi SeiZleba gamoyenebuli iyos, rogorc komutatori, romelic garkveuli droiT ayovnebs Zabvas izolaciis garRvevis gareSe, aseve gamoyenebuli SeiZleba iyos,

rogorc CamrTveli, romelic aRmoCndeba sxvadasxva amplitudis mqone impulsuri Zabvis zegavlenis qveS.

2) unda gaaCndeT mcire induqciuroba.

3) hqondeT amuSavebis (amoqmedebis) Sesabamisi sizuste, romelic aseve damokidebulia paralelurad CarTul ganmmuxtavebis raodenobaze.

4) gaaCniaT SedarebiT mcire winaRoba da garkveuli xanmdegoba.

ganvixiloT zogierTi ganmmuxtavis moqmedeba da mowyobiloba.

umartivesi vakuumuri ganmmuxtavi warmoadgens cilindrul kameras saizolacio masaliT da liTonis eleqtrodebiT. saizolacio masalad gamoyenebulia faifuri, mina, organuli mina, polieTileni, ftoroplasti da a. S. eleqtrodebis masalad gamoyenebulia liTonebi, romlebic maRal temperaturaze orTqldebian.

vakuumuri ganmmuxtavi gamoirCeva Semdegi upiratesobebiT: mcire sakuTari induqciurobiT, denis kargi gatarebiT, mZlavri dartymiTi talRebis ar arsebobiT, uxmauro muSaobiT. muSa Zabvis Secvlisas ganmmuxtavebi ar saWiroeben meqanikur regulirebas. ganmmuxtavis muSa Zabva icvleba 100-300v-dan 150kv-mde, komutaciis deni ki aRwevs $3\cdot10^6a$.

didi denebis komutaciisas, rodesac energiis mniSvnelovani nawili gamoiyofa kameris eleqtrodebsa da kedlebze, xdeba masalis aorTqleba da gazis wnevis zrda moculobaSi im donemde, rodesac ganmmuxtavebi veRar akaveben muSa Zabvas, amitom aucilebelia vakuumuri moculobis amotumbva.

ganmmuxtavis amuSaveba gamowveulia:

1) neitraluri gazis gaSvebiT ganmuxtvis kameraSi.

2) naperwkliani anTebiT, romlis drosac warmoiqmneba mokletalRuri radiacia da ionizirebuli garemo.

3) plazmuri nakadiT, romelic miedineba kameraSi sxvadasxva tipis inJeqtorebidan.

4) lazeruli afeTqeba, romelic iwvevs myari sxeulebis aorTqlebas vakuumur moculobaSi da warmoiqmneba orTqlis ionizacia.

ganmuxtvis eleqtruli simtkice ganisazRvreba Sida da gare izolaciis zedapirze ganmuxtvis ZabviT. rac Seexeba Sida vakuumur izolacias masSi ZiriTad rols TamaSobs ara marto izolaciis zedapiruli gadafarvis Zabva vakuumSi, aramed izolaciis unari SeinarCunos an swrafad aRidginos Tavisi saizolacio Tvisebebi didi denis gavlis Semdeg, rasac Tan axlavs Zlieri gazis gamoyofa, eleqtrodebis da kameris kedlebis masalis aorTqleba.

vakuumuri ganmuxtvis eqsluataciis procesma aCvena, rom Sida vakuumuri izolaciis maxasiaTeblebi damokidebulia komutirebadi batareis energiaze. didi denis gavlis Semdeg mkveTrad mcirdeba eleqtruli simtkice, romlis aRdgena yovelTvis arxerxdeba.

gamoTqmulia varaudi imis Sesaxeb, rom ganmmuxtavma izolaciuri Tvisebebi SeiZleba dakargos maSin, rodesac liTonis orTqli ileqeba izolaciis zedapirze. ganmmuxtavis eleqtruli simtkicis Semcireba didi denebis komutaciisas gamowveulia ara liTonis orTqlis daleqviT kedlebze, aramed liTonis zedapiris mier airebis absorbciiT. am daskvnis sasargeblod metyvelebs kerZod, liTonis kvalis ar arseboba izolaciis zedapirze ganmmuxtavis xangrZlivi eqspluataciis Semdeg [12].

ganmmuxtavebis Cveulebrivi muSaobis reJimi damokidebulia batareis da datvirTvis parametrebze.

ganmmuxtavebze eqsperimentebi Catarebulia, roca kondensatoruli batareis tevadoba aris 9mkf, xolo Zabva 40kv-mdea.

sankt-peterburgis politeqnikur institutSi vakuumur ganmmuxtavSi gazomilia denis ganawileba organuli minis kedlebze 150kv Zabvis dros. denis ganawileba ganmuxtvis kameraSi gazomilia rogovskis ori qamris daxmarebiT. pirveli qamari 150mm diametriT moicavs centralur ares, eleqtrodis farTobis 20%-s.

rogovskis meore qamari 250mm diametriT moicavs eleqtrodis farTobis 50%-s. qamrebi izolirebulia polieTilenis firfitiT. ganmuxtvis muSa konturSi gazomilia denis ganawileba 150khc sixSireze, roca batareis ganmuxtvis Zabva 70kv-ia, xolo denis amplituduri mniSvneloba 900ka.

ganmmuxtavis xanmedegoba _ warmoadgens maxasiaTebels, romelic gansazRvravs vakuumuri ganmmuxtavis eqspluataciis xangrZlivobas, romelic ar aRemateba 4500 ganmuxtvas.

zemoT moyvanili ganmmuxtavebis tipebi gaTvlilia minimum 10^3 CarTvaze. didi yuradReba eqceva iseT ganmmuxtavebs, romelTac SeuZliaT didi denis gatareba, maT moqmedebas Semcirebul droSi, eleqtrodebis cveTas, romelic dakavSirebulia energiis batareasTan, sixSiresTan da denis amplitudasTan, eleqtrodebis siTbotevadobas da siTbogamZleobas muSa da impulsur reJimebSi specialuri gacivebis gareSe.

ionur ganmmuxtavebSi gamoyenebulia rkaluri, naperwkluri an mRvivara ganmuxtvis movlenebi. ufro farTod gamoiyeneba rkaluri ganmuxtva, romlisTvisac ganmuxtvis SualedSi damaxasiaTebelia Zabvis vardna da didi denebi. ganmmuxtavebi _ esaa oreleqtrdiani an sameleqtrodiani xelsawyo, romlis korpusi damzadebulia minis an metalokeramikisagan. ionuri ganmmuxtavis saWiro parametrebia: garRvevis Zabva 75-20000v, ganmuxtvis deni 100-1000a, ganmuxtvis energia, izolacia, ganmuxtvebis dasaSvebi ricxvi 107-mde, muSaobis dro [23].

ignitronuli ganmmuxtavi Sedgeba anodisa da kaTodis eleqtrodebisagan, aseve anmTebi eleqtrodisagan. anodis minis izolatoris dazianebis Tavidan acilebisTvis xelsawyo aparaturaSi damagrebulia Semdegi TanmimdevrobiT: xelsawyo moTavsebulia gankuTvnil budeSi. flancis xvrelebSi Camagrebulia WanWikebi ise, rom qanCiT ar aris daWerili. xelsawyos samagri salte anodTan damzadebulia ori gasaRebiT, romelic dakavSirebulia eqvswaxnagas gamomyvanTan. Semdeg flancis simagrisTvis WanWikebs qanCiT uWeren, romelic uzrunvelyofs saimedo

eleqtrul kontaqts. xelsawyo pirvelad CarTvisas 15wT-is ganmavlobaSi mudmivad muSaobs. Zabva anodze icvleba 2kv-dan muSa mniSvnelobamde. wylis temperaturaa 10^0C, xolo gamacivebeli wylis temperatura icvleba 25^0C-dan 35^0C-mde.

eqspluataciisas xelsawyo teqnikurad daculia, radgan misi samuSao korpusi Zabvis qveSaa. eqspluataciis reJimis dros xelsawyos zRvruli mniSvnelobebia: Zabva anodze 0.1_20kv, xolo anodis impulsuri deni 100ka.

transportirebisas da eqspluataciisas xelsawyo daculia mkveTri dartymebis, ryevebisa da rRvevebisagan. hermetulobis darRvevisas vercxliswyali, romelic moTavsebulia xelsawyos SigniT SeiZleba daiRvaros.

didi simZlavreebis komutacia, rogorc wesi, xorcieldeba airganmmuxtavi xelsawyoebiT. mniSvnelovanwilad maT ganviTarebaSi miRweuli warmatebis Sedegad warmoiqmna unikaluri mowyobilobebis Seqmnis teqnikuri SesaZlebloba, Tumca am mowyobilobebs (xelsawyoebs) gaaCniaT principuli naklovanebebi, rac ganpirobebulia TviT airebSi ganmuxtvis procesebis xasiaTiT. pirvel rigSi, es aris amuSavebis arastabiluroba, rac arTulebs rTuli sistemebis sinqronizacias da eqspluataciis mcire vada, rac dakavSirebulia eleqtrodebis swraf daSlasTan.

garda amisa, airganmmuxtavi mowyobilobebi rTulia eqspluataciaSi, arasakmarisad saimedoa da metismetad mgrZnobiare gare zemoqmedebisas. daaxloebiT 10-15wlis ganmavlobaSi Zalovani gardamqmneli teqnikidan, isini mTlianad Seicvalnen mZlavri naxevargamtaruli mowyobilobebiT _ tiristorebiT da tranzistorebiT. varaudoben, rom naxevargamtaruli teqnikis ganviTareba agreTve daipyrobda didi simZlavris impulsur da maRalsixSirul teqnikasac. miuxedavad TvalsaCino miRwevebisa, tiristorebisa da tranzistorebis ganviTarebaSi es mainc ar moxda principuli xasiaTis mizezebis gamo. naxevargamtaruli xelsawyoebiT didi simZlavreebis komutacia xdeba garemos gamtarobis mkveTri gazrdis gziT, romelsac sawyis mdgomareobaSi gaaCnia maRali

winaRoba da blokavs xelsawyoze modebul gare Zabvas. aseT garemos (ares) Cveulebriv warmoadgens $p-n$ gadasvlis ukuSeqceuli, Zlieri veliT dasustebuli moculobiTi muxti. am areSi gamtarobis mkveTri zrda xdeba maSin, roca mas avseben kargi gamtarobis mqone eleqtrul _ xvreluri plazmiT.

komutirebadi simZlavris kuTri sididis fundamentaluri fizikuri SezRudvebi naxevargamtaruli xelsawyoebisaTvis ZiriTadad dakavSirebulia plazmaSi muxtis matareblebis SedarebiT dabali moZraobis unarTan da koncentraciasTan, agreTve SedarebiT dabal muSa temperaturasTan, ris gamoc, gamoikveTa sakiTxi, rasac mivyavarT gamtari garemos muSa moculobis Seqmnis aucilebloBasTan. plazmaSi SedarebiT mcire difuziuri sigrZis mniSvnelobebi ar iZleva moculobis gazrdis saSualebas eleqtrodebs Soris manZilis gazrdis xarjze, rogorc es xdeba airganmmuxtav xelawyoebSi da, amitom komutirebadi simZlavris gazrda SeiZleba moxdes ZiriTadad dengamtari arxis farTobis gazrdis xarjze. Sasabamisad, komutaciis zRvruli maxasiaTeblebi ganisazRvreba mdgradi mokle plazmuri arxebis swrafi Seqmnis SesaZlebloBiT didi farTobis mqone diskis saxiT garemos maRali winaRobiT. yvelaze mZlavr Tanamedrove naxevargamtarul gadamrTvelebSi (bipolarul tranzistorSi da tiristorSi) plazmuri arxebi formirdeba Zlier legirebuli emiteruli fenebis (Sreebis) matareblebis inJeqciiT [25].

nax. 3.1-ze naCvenebia mZlavri tiristorebis naxevargamtaruli struqtura, romelic Sedgeba sxvadasxva gamtarobis tipis oTxi Srisagan. es Sreebi warmoSobs sam $p-n$ tipis gadasvlas. ori gare emiteri CarTulia gamtarobis mimarTulebiT, xolo centraluri (koleqtoruli) blokavs xelsawyoze modebul Zabvas. gadarTvisas moculobiTi muxtis garemo Sevsebulia plazmiT. gadarTva inicirdeba impulsuri denis gavliT wredSi emiteri-baza, Txeli bazis Sreebis gaswvriv. emiteruli n^+-p gadasvliT eleqtronebis inJeqcia lokalizdeba viwro arxSi (aseuli mikronis rigis) emiter-bazis sazRvris gaswvriv.

tiristorSi am arxis sigane drois ganmavlobaSi izrdeba CarTuli mdgomareobis gavrcelebis gamo, magram am procesis siCqare Zalian mcirea (0.1 _ 0.005 mm/mkwm).

tranzistorSi ki arxis sigane ar aris damokidebuli droze da mcirdeba denis sididis gazrdisas. aseTi lokalizacia praqtikulad SeuZlebels xdis didi farTobis mqone dengamtari arxis Seqmnas da amitom naxevargamtaruli xelsawyoebi, romlebic emyarebian komutaciis ZiriTad principebs, ver uweven konkurencias magaliTad, airganmuxtavebs, romelTac SeuZliaT simZlavris swrafi komutacia mega da giga vatis diapazonis areSi. amave dros lazeruli, amaCqareblebis, TermobirTvuli energetikis, radioteqnikis da lokaciuri teqnikis Tanamedrove done moiTxovs swored naxevargamtaruli xelsawyoebiT amave diapazonis simZlavreebis komutirebas, romlebsac gaaCniaT upiratesobebi: eqspluataciis didi xangrZlivoba, saimedooba, maRali mqk da xanmedegoba, rac Zlier mniSvnelovania gare zemoqmedebisas.

pikowamis diapazonSi arsebuli naxevargamtaruli xelsawyoebi axdenen mxolod 1vt simZlavris komutacias. am diapazonis mZlavri komutatorebis ararseboba seriozul sirTules uqmnis salokacio da saregistracio sistemebis axali saxeobebis ganviTarebas.

naxevargamtaruli xelsawyoebiT didi simZlavreebis komutacia mikro, nano da piko wamis diapazonSi radikalurad Seicvala ukanasknel bolo ramdenime weliwadSi, mas Semdeg rac iofes saxelobis fizika-teqnikis institutSi damuSavebuli iqna komutaciis ori axali principi _ mmarTveli plazmuri fenisa da Seyovnebuli dartymiTi _ saionizacio talRis daxmarebiT, rac saSualebas iZleva gaizardos xelsawyos komutirebadi simZlavre mikrowamis diapazonSi erTi rigiT, xolo nanowamis diapazonSi ori-sami rigiT da pikowamis diapazonSi TiTqmis oTxi rigiT.

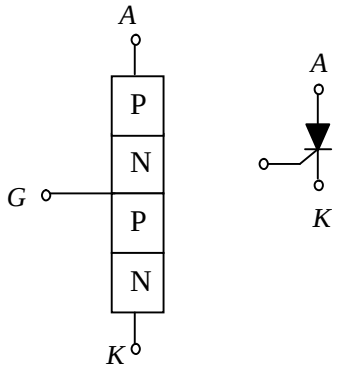
komutaciis maxasieTeblis aseTma mkveTrma gaumjobesebam bunebrivad SesaZlebeli gaxada axali sistemebis da mowyobilobebis Seqmna aseT xelsawyoebze dayrdnobiT.

bolo ramdenime wlis manZilze, iofes saxelobis fizika-teqnikis institutSi Catarda intensiuri gamokvlevebi, sadac Seiqmna ramdenime axali tipis mZlavri naxevargamtaruli xelsawyoebi unikaluri maxasiaTeblebiT. kerZod, plazmuri _ marTvis tiristori da tranzistori (mikrowamis diapazonis), dioduri, tranzistoruli da tiristoruli tipis impulsuri amaCqarebleebi (nanowamis diapazonis). agreTve komutaciis principebze dayrdnobiT Seyovnebuli darTymiTi _ saionizacio talRis daxmarebiT Seiqmna dioduri, tranzistoruli da tiristoruli tipis impulsuri amaCqareblebi (nano da pikowamis diapazonis) [40].

mTeli es kompleqsi ZiriTadad Seiqmna axali mimarTulebisaTvis, romelsac uwodeben Zalovan naxevargamtarul impulsur da maRalsixSirul eleqtronikas [31].

1.5. tiristoruli ganmmuxtavebi

tiristori _ es aris naxevargamtaruli xelsawyo, romelic Sesrulebulia naxevargamtaris oTxfeniani struqturis $p-n-p-n$ tipis monokristalis safuZvelze, romelsac gaaCnia eleqtruli ventilis Tvisebebi da arawrfivi wyvetili volt-amperuli maxasiaTebeli. naxevargamtaruli xelsawyo mmarTveli sami eleqtrodiT, romelic Sedgeba Tanmimdevrulad ganlagebuli oTxi *p* da *n* tipis siliciumis Sreebisgan, uwodeben tiristors. naxevargamtaruli xelsawyo oTxfeniani struqturiT warmodgenilia naxazze 1.8.



nax. 1.8

nax. 1.8. A _ anodi, K _ kaTodi, G _ mmarTveli eleqtrodi.

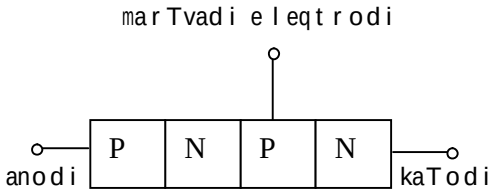
p _ struqturis kidura ares, romelic CarTulia wyaros dadebiT polusze uwodeben anods, xolo *n* _ struqturis kidura ares, romelic CarTulia wyaros uaryofiT polusze uwodeben kaTods. oTxpolusian $p-n-p-n$ tipis xelsawyos SeiZleba hqondes ori mmarTveli eleqtrodi (baza) mierTebuli Sida SreebTan. xelsawyos, mmarTveli eleqtrodebis gareSe, uwodeben diodur tiristors (an dinistors), xolo xelsawyos erTi mmarTveli eleqtrodiT uwodeben triodul tiristors (an tiristors) [32].

tradiciuli tiristori, romelic warmoadgens naxevargamtarul ventils, farTod gamoiyeneba impulsuri teqnikis mowyobilobebisTvis. CarTul mdgomareobaSi maT axasiaTebT Zabvis mcire vardna, gaaCniaT denis gadatvirTvis maRali unari da martivi bipolaruli teqnologiis gamo aqvT Sesabamisad dabali TviTRirebuleba. misi nakli vlindeba mokle komutaciisas da impulsuri denis Zalian didi amplitudisas. es dakavSirebulia CarTuli mdgomareobis sakmarisad nel procesebTan, romelic vrceldeba mmarTveli eleqtrodidan $p-n$ gadasvlis gare sazRvramde. tradiciuli tiristoris aseTi Tavisebureba ganisazRvreba misi gamoyenebiT denis komutaciisas miliwamis diapazonSi. tiristoris impulsuri Tvisebis gaumjobeseba miiRweva mmarTveli eleqtrodis konstruqciis gamoyenebis xarjze, romelic Tanabradaa ganlagebuli siliciumis struqturis mTel farTobze. es drois Semcirebis saSualebas iZleva sruli CarTvisas da tiristoris sakomutacio Tvisebebis gaumjobesebisas.

siliciumiani marTvadi ventili warmoadgens kargad cnobil tiristorul tips. mas aqvs sami gamomyvani (anodi, kaTodi da mmarTveli eleqtrodi) da gamoiyeneba rogorc gadamrTvelebi. marTvadi ventili arsebiTad warmoadgens gammarTvels, romelsac SeuZlia denis marTva mxolod erTi mimarTulebiT. misi upiratesoba mZlavr (Zalovan) tranzistorebTan SedarebiT aixsneba imiT, rom maT SeuZliaT didi denebis marTva gare wredSi mokle mmarTveli signalis daxmarebiT. igi atarebs dens mmarTveli signalis moqmedebis Sewyvetis Semdegac. Tu denis sidide nulamde

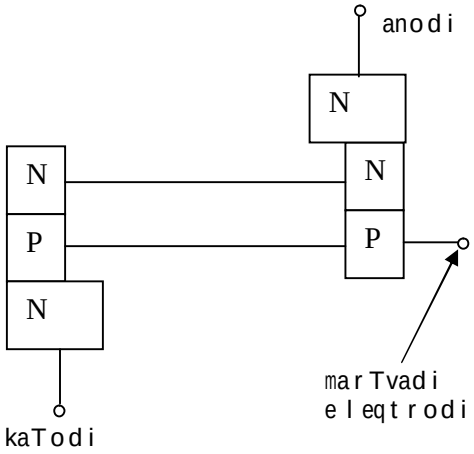
ecema, maSin is iketeba da awvdis axal mmarTvel signals gaxsnil mdgomareobaSi dasabruneblad [35].

siliciumiani marTvadi ventili _ es aris myarsxeulovani mowyobiloba, romelic damzadebulia siliciumis difuziuri meTodiT. igi Sedgeba oTxi ***p da n*** tipis naxevargamtaris Sreebisgan, romlebic ganlagebulia TanmimdevrobiT. sqema naCvenebia naxazze 1.9.



nax. 1.9

misi eqvivalenturi sqemaa



nax. 1.10

siliciumiani marTvadi ventilis CarTva xdeba dadebiTi mmarTveli ZabviT, xolo misi gamorTva xdeba anod-kaTods Soris Zabvis SemcirebiT nulamde. rodesac igi CarTulia da atarebs dens kaTodidan anodisken, misi gamtaroba pirdapiri mimarTulebiT sakmarisad didia. Tu Seicvleba anod-kaTods Soris Zabvis polaroba wredSi, romlis gamtarobac mkveTrad mcirdeba, maSin masSi gava mxolod gaJonvis mcire deni [34].

rodesac siliciumiani marTvadi ventili gamoiyeneba mudmivi denis wredSi, datvirTvidan misi gamorTvis martivi meTodi

Zabvis moxsnis gareSe ar arsebobs. es problema gadaiWreba maSin, Tu mas paralelurad miuerTdeba CamrTveli.

mmarTveli plazmuri Sris daxmarebiT komutacia sakmaod martivia. magaliTad, Tu tiristoruli tipis xelsawyoSi raime meTodiT koleqtoruli $p-n$ gadasvlis sibrtyeSi Seiqmneba eleqtronul _ xvreluri plazmis erTgvarovani Sre, maSin gare Zabva am Sridan mTel farTobze erTgvarovnad gadaanacvlebs xvrelebs p areSi, xolo eleqtronebs n areSi. es gadamtanebi, romlebic ZiriTadia bazuri p da n areebisTvis, adablebs ra gare emiterul $p-n$ gadasvlebis potenciur barierebs, iwvevs araZiriTadi gadamtanebis inJeqcias Sesabamis bazur areSi da xelsawyos gadarTavs Cveulebrivi tiristoruli meqanizmiT. Cveulebrivi sameleqtrodiani tiristorisgan gansxvavebiT gadarTva warmoebs erTgvarovnad da erTdroulad xelsawyos mTel farTobze. amrigad, mmarTveli eleqtrodis Secvla erTgvarovani plazmuri SriT saSualebas iZleva moxdes plazmuri dengamtari arxis formireba farTobiT, romelic tolia siliciumis firfitis farTobisa. radgan, aseTi Sris Seqmna sakmaod rTulia, amitom Seswavlili iqna sxvadasxva meTodebi: koleqtoruli gadasvlis impulsur-zvaviseburi garRveva, dartymiTi ionizacia zemaRal sixSirul velSi, ionizacia sinaTlis mZlavri koherentuli da arakoherentuli impulsiT. yvela am meTodiT miiRes sakmaod kargi Sedegebi, magram isini metismetad rTuli aRmoCnda teqnikuri TvalsazrisiT. yvelaze xelsayreli aRmoCnda e.w reversiul-inJeqciuri marTva, romlis drosac mmarTveli plazmuri Sre warmoiqmneba xelsawyoze modebuli Zabvis polarobis uecari cvlilebiT. am meTodis gamoyenebiT Seiqmna xelsawyoebis sami axali klasi. gadamrTveli xelsawyoebis or klass (tiristoris da tranzistoris plazmurad marTvadi analogebi) uwodes Sesabamisad reversiulad CarTvadi dinistori (rCd) da reversiulad marTvadi tranzistori (rmt). es xelsawyoebi muSaoben mikro da submikrowamis diapazonebSi. nanowamebis diapazonisTvis damuSavebuli

iqna impulsebis Zlieri dioduri amaCqarebeli-dreifuli diodi mkveTri aRdgeniT [53].

nebismieri daniSnulebis magnitur-impulsuri mowyobilobis erT-erT ZiriTad nawils warmoadgens komutatori, romlis saSualebiT maRali Zabvis impulsuri kondensatorebis batareaSi dagrovili energia ganimuxteba induqtorze da generirdeba Zlieri impulsuri magnituri veli. es ukanaskneli axdens ra Zalovan zemoqmedebas eleqtrogamtar garemoze, impulsurad aRagznebs sadiagnostiko obieqts da xdeba misi reaqciis registrireba. magnitur-impulsuri mowyobilobis reaqciis analiziT miRebuli diagnostikis Sedegebi mniSvnelovnad aris damokidebuli impulsuri aRgznebis intensivobaze, impulsis formasa da xangrZlivobaze, speqtralur simkvrivesa da sxva parametrebze.

komutatorebi efeqturi muSaobisTvis unda akmayofilebdnen rig moTxovnebs, romlebic xSirad winaaRmdegobrivia. upirveles yovlisa, maT unda uzrunvelyon damuxtvis procesSi kondensatorebis batareis saimedo ganmxoloeba induqtorisagan usafrTxoebis mizniT da Semdgom, maTi saimedo SeerTeba datvirTvasTan minimaluri sigrZis salteebiT, raTa uzrunvelyofili iyos ganmuxtvis konturis minimaluri "parazituli" induqciuroba. sasurvelia, rom komutatorSi ganmuxtvis pirdapiri deniani sadeni moculi iyos ukusadeniT, e.i. komutatoris konstruqcia Sesrulebuli iyos koaqsialuri kabelis principiT.

sadiagnostiko obieqtze magnitur-impulsuri mowyobilobis SesamCnevi zemoqmedeba SeigrZnoba, rodesac impulsuri magnituri velis induqciis pikuri mniSvneloba Seadgens 8–10 teslas. induqciis 30–50 teslas mniSvnelobisas adgili aqvs liTonis zedapiris mniSvnelovan deformaciebs; 50_70 teslas dros xdeba liTonis zedapiris molRoba, xolo 90_100 teslas dros xdeba liTonis aorTqleba. aseTi velebis generirebisaTvis saWiroa aseulobiT kiloamperi denebis komutireba.

teqnikuri fizikis dargisTvis gankuTvnil, teqnologiuri Tu gamosacdeli daniSnulebis mZlavr magnitur-impulsur

danadgarebSi gamoyenebulia sankt-peterburgis da xarkovis politeqnikur institutebSi damuSavebuli sahaero ganmmuxtavebi, riazanis radioteqnikuri qarxnis ignitronebi ИРТ-1, ИРТ-2, ИРТ-3, ИРТ-4, firma „General Electric''-s ganmmuxtavebi GL-7171, GL-7703, romelTac aqvT marTvis eleqtrodi, Sesrulebuli koaqsialuri kabelis pricipiT, SeuZliaT aseulobiT kiloamperi denis komutireba. komutirebis Semdeg dens atareben orive mimarTulebiT da aqvT SezRuduli resursi (10^3-10^4 amuSaveba). agreTve cnobilia, ionuri (tiratronebis) da naxevradgamtariani (tiristoruli) komutatorebi [57].

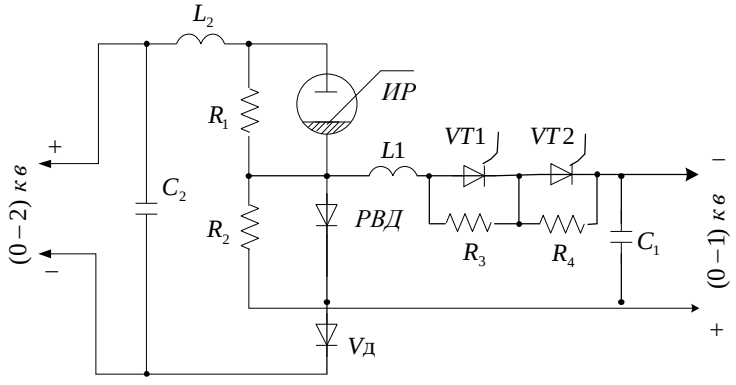
xSirad, gansakuTrebuli moTxovnebi waeyeneba induqtorSi gamavali ganmuxtvis denis formas _ iyos is aperioduli, milevadi sinusoiduri, Tu Zlier milevadi (sinusoidis pirveli naxevartalRis formis), es ukanaskneli an aperioduli reJimi miiRweva ganmuxtvis konturSi damatebiTi an arawrfivi winaRobis SeyvaniT. magaliTad, tiritis an vilitis korborunduli winaRobebiT. am elementebs aqvT rbili volt-amperuli maxasiaTebeli, e.i. denis Semcirebisas maTi winaRoba izrdeba, rac adidebs denis milevis siCqares. am dros denis impulsi aris unipolaruli.

literaturaSi cnobilia, unipolaruli formis impulsis formirebis sqemuri gadawyveta (kroubaris sqema), rodesac induqtori Suntirdeba damatebiTi komutatoriT (sahaero an ignitronuli ganmmuxtaviT) drois im momentisTvis, rodesac deni aRwevs maqsimalur mniSvnelobas da imis magier, rom induqtoris magnitur velSi dagrovili energia dabrundes kondensatorebSi, xdeba misi gamoyofa siTbos saxiT Suntisa da induqtoris winaRobebSi, ris gamoc, mkveTrad izrdeba denis Semcirebis siCqare. ganmuxtvis konturis parametrebis SerCeviT miiRweva ganmuxtvis denisTvis erTeulovani impulsis forma.

cnobilia, agreTve magnitur-impulsuri mowyobiloba tiristoruli komutatoriT, sadac naxevarsinusoiduri formis 10mkwm xangrZlivobis erTeulovani impulsuri denis maqsimaluri mniSvneloba Seadgens 3ka. komutatori Seicavs oTx mimdevrobiT

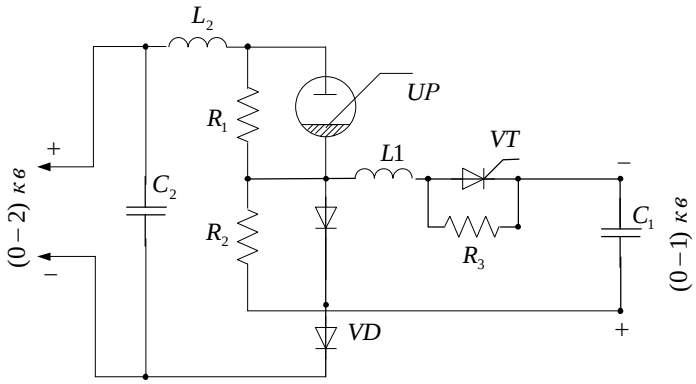
SeerTebul IX klasis ТИ 3000 tipis impulsur tiristors da konstruqciulad Sesrulebulia koaqsialuri kabelis principiT. aRniSnuli tiristorebisaTvis denis cvlilebis siCqare ar aRemateba 800a/mkwm, amitom magnitur-impulsuri mowyobilobis SesaZleblobebi SezRudulia da generirebuli impulsuri magnituri velis induqciis pikuri mniSvneloba Seadgens 6–8 teslas. ufro Zlieri impulsuri magnituri velebis generirebisaTvis naxevargamtariani komutatorebiT saWiroa gamoyenebuli iqnes naxevargamtaruli xelsawyoebi, romelTa gaReba xdeba impulsuri tiristorebisgan gansxvavebuli meTodiT [68].

magnitur-impulsuri danadgaris saimedo eqspluataciisTvis Zalzed mniSvnelovania misi, rogorc eleqtruli mowyobilobis diagnostikis meTodebisa da saSualebebis SemuSaveba. saimedoobis TvalsazrisiT misi SedarebiT susti rgolebia _ induqtori da komutatori. naxevargamtaruli komutatoris gamoyeneba mniSvnelovnad aumjobesebs danadgaris saimedoobas, magram kvlav aqtiuria impulsuri denis xangrZlivobisa da pikuri mniSvnelobis gansazRvra, denisa da Zabvis cvlilebaTa siCqaris dadgena. am mizniT magnitur-impulsuri sistemebi aRWurvilia impulsuri denisa da Zabvis parametrebis gasazomi saSualebebiT. garda amisa, metad mniSvnelovania komutatoris reversiulad CarTvadi dinistoris winaswari diagnostika, rac SesaZlebelia nax. 1.11-ze naCvenebi eleqtruli sqemis saSualebiT.



nax. 1.11

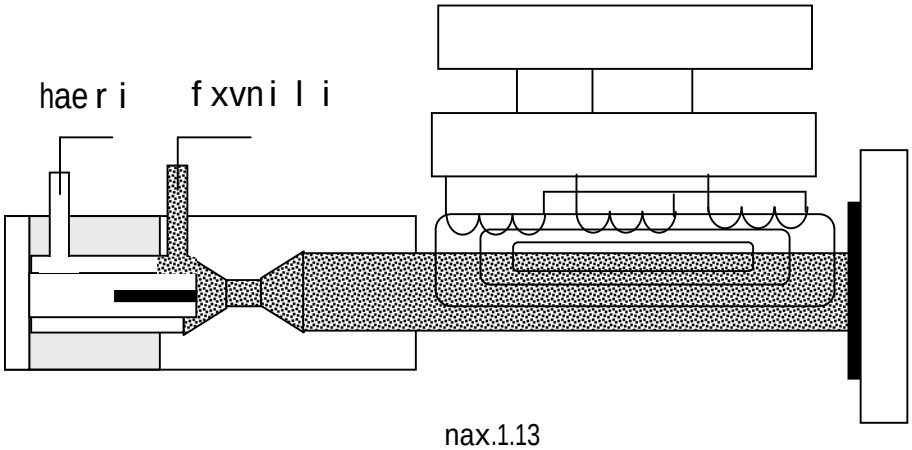
sqemaSi gaTvaliswinebulia C_2 kondensatori, rogorc kvebis wyaro regulirebadi ZabviT 0_2kv. kondensatori ganimuxteba L_2 droselisa da UP ignitronuli ganmmuxtaviT reversiulad CarTvad dinistorze da aformirebs amukanasknelis datvirTvas impulsuri deniT. ignitronuli ganmmuxtavis daniSnulebaa dinistoris muSaobis pirdapiri da reversiuli reJimebis gancalkeveba imavdroulad impulsuri reversiuli denis amplitudisa da xangrZlivobis SenarCunebiT C_2 kondensatorze Zabvis sxvadasxva mniSvnelobisaTvis. dinistori eSveba VT tiristoris CarTviT. VD diodi gamoricxavs UP ignitronis uku anTebis C_2 kondensatoris gadamuxtvisas.



nax. 1.12

sadisertacio naSromSi moyvanilia agreTve plazmuri Wavlis aCqarebis meTodis damuSavebis Sedegebi, razedac miRebulia saqarTvelos patenti GE P 2008 4350 B. AP 2006 009213.

es meTodi gamoyenebuli SeiZleba iqnes eleqtrorkalur plazmatronebSi, sadac reversiulad CarTvadi dinistoriT xdeba plazmaze damuxtuli kondensatorebis batareis gadamuxtva, plazmaSi denis simkvrivis mkveTri gazrda da misi Semdgomi aCqareba msrboli magnituri velis saSualebiT. Sesabamisi magnitur-impulsur-plazmuri sistemis principuli sqema naCvenebia naxazze 1.13.



nax.1.13

es sistema uzrunvelyofs plazmatronis saqSenidan plazmis gamodinebis siCqaris mkveTr zrdas da detonaciuri teqnologiebis magnitur-impulsur-plazmuri teqnologiiT Canacvlebis liTonis detalebis dafarvisas maTi cveTamedegobis da sxva meqanikuri Tvisebebis gasaumjobeseblad. rogorc cnobilia, dabal temperaturuli plazma warmoadgens karg eleqtrogamtars da amitom SesaZlebelia masze kondensatoris batareis gadamuxtvisas plazmaSi energiis simkvrivis gazrda da Sesabamisad, masSi arsebuli ingredientebis (naxSiris fxvnili) liTonis zedapirze dajaxebis siCqarisa da temperaturis mkveTri gazrda, rac xels uwyobs liTonis zedapirze abraziuli cveTisadmi medegi Txeli fenis warmoqmnas [18].

2. შედეგები და მათი განსჯა

Tavi II. piezoeleqtruli aCqarebis gamzomi gardamsaxebi.

2.1 piezoeleqtruli gamzomi gardamsaxebis gamoyenebis are, gamzomi gzrdamsaxebis ZiriTadi maxasiaTeblebi.

maRalsiCqaruli, intensiuri datvirTvebisTvis gankuTvnili teqnologiuri Tu diagnostikuri daniSnulebis danadgarebis gamokvlevisas, imis gamo rom meqanikur Zabvebs, deformaciebs, aCqarebebs xSirad aqvT talRuri xasiaTi, masiurad gamoiyeneba sxvadasxva saxis maRalsixSiruli miniaturuli gamzomi gardamsaxebi, maT Soris piezoeleqtruli gamzomi gardamsaxebi, raTa Tavidan avicileT gamzomi gardamsaxis bazis gaswvriv gasazomi signalis integrirebiT gamowveuli cdomilebebi. amave dros danadgarebis dinamkiuri gamocdebisas miRebuli informaciis srulfasovani damuSavebisaTvis aucilebelia gamoviyenoT gamzomi gardamsaxebis dinamikuri maxasiaTeblebis sruli paketi. rogorc wesi, miniaturuli gamzomi gardamsaxebi warmoadgens maRalsixSirul rxeviT sistemebs da maTi dinamikuri maxasiaTeblebis gansazRvra warmoadgens rTul teqnikur problemas. misi gadawyveta standartuli dartymiTi meqanikuri stendebiT (urnalebi) SeuZlebelia, vinaidan am dros ganviTarebuli impulsuri datvirTvis xangrZlivoba miliwamebis diapazonSia da gamzomi gardamsaxis xanmokle, mikrowamebis xangrZlivobis impulsebiT datvirTva SesaZlebeliamxolod uinercio (masis armqone) damrtymeli instrumentis gamoyenebiT [60].

milidan mikroteqnologiebze gadasvla SesaZlebeli gaxda afeTqebis talRis an impulsuri magnituri velis gamoyenebiT. maT Soris didi upiratesoba aqvs magnitur-impulsur teqnologias, romlis danergvas xeli Seuwyo Zlieri impulsuri magnituri velis generatorebis, didi sididis impulsuri denebisa da Zabvebis teqnikis ganviTarebam, mrewvelobis mier maRali Zabvis impulsuri kondensatorebisa da ganmmuxtvelebis aTvisebam.

diagnostikuri da teqnologiuri daniSnulebis nebismieri magnitur-impulsuri sistemis moqmedeba damyarebulia eleqtromagnituri velis eleqtrogamtar garemoSi gavrcelebisa da masze Zaluri zemoqmedebis movlenebze. impulsuri magnituri veli saSualebas iZleva ganaviTaros Zalze xanmokle mikrowamebis diapazonis Zaluri zemoqmedeba gamosacdel obieqtze [58].

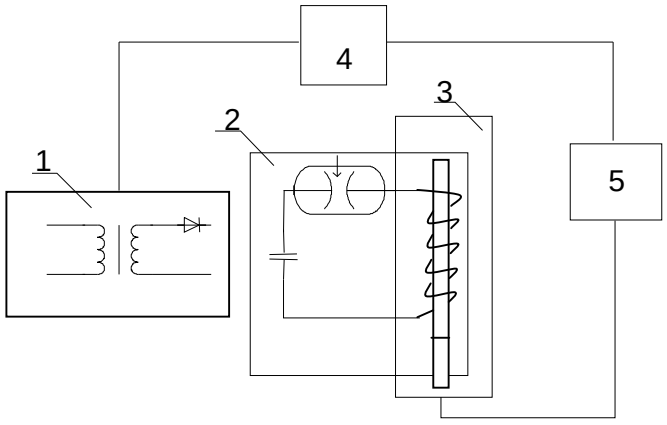
sxvadasxva saxis masalebis an namzadebis dinamikuri maxasiaTeblebis gansazRvrisaTvis saWiroa, rom cilindruli formis liTonis ReroSi, romelic meqanikuri talRagamtaris rols asrulebs, aRiZvras mikrowamebis diapazonis xangrZlivobis meqanikuri Zabvebi, deformaciebi da aCqarebebi. amave dros, standartuli meqanikur dartymaze gamosacdeli stendebi (meqanikuri qanqariani an sxva tipis urnalebi) saSualebas iZleva ganviTardes miliwamebis diapazonis impulsuri datvirTebi. arsebul meqanikur dartymaze gamosacdel stendebSi gamoyenebulia ori myari sxeulis garkveuli siCqariT dajaxebis efeqti, romlis drosac dartymaSi monawile sxeulebis kinetikuri energia nawilobriv gadadis am sxeulebis impulsuri deformaciis energiaSi. sxeulebSi warmoSobili impulsuri deformaciebis xangrZlivoba da intensiuroba damokidebulia dartymis siCqareze, dartymaSi monawile sxeulebis masaze, masalaze, sixisteze, geometriul zomebsa da konfiguraciaze. amis gamo, meqanikur dartymiT stendebSi (urnalebi) xanmokle impulsebis miReba SezRudulia da Semoifargleba miliwamebis diapazoniT, mikrowamebis diapazonze gadasvla maTi saSualebiT principulad SeuZlebelia.

ufro xanmokle impulsuri deformaciebi da meqanikuri Zabvebi aRiZvreba myar sxeulebSi maTi datvirTviT afeTqebis talRiT, gamowveuli asafeTqebeli nivTierebis saTanado ganlagebiTa da inicirebiT an „umaso” damkvrelis _ impulsuri magnituri velis saSualebiT. am dros impulsuri zemoqmedebis xangrZlivoba mikrowamebis diapazonisaa da miiRweva deformaciis didi siCqareebi, rac saSualebas iZleva davadginoT masalebis dinamiuri maxasiaTeblebi (dinamiuri denadobisa da simtkicis zRvrebi).

aseve, myar sxeulSi _ meqanikur talRagamtarSi mikrowamebis diapazonis impulsuri deformaciis warmoSobisas talRagamtaris torcebi asruleben moZraobas maRali donis impulsuri aCqarebebiT, rac saSualebas iZleva torcze damagrebuli namzadi (gamzomi gardamsaxi, naxevargamtariani diodi, tranzistori, mikrosqema da sxva) gamokvleul iqnes dartymamedegobasa da dartymamdgradobaze.

rogorc avRniSneT, milidan mikroteqnologiebze gadasvla SesaZlebelia uinercio damkvrelis gamoyenebiT, romlis roli SeiZleba Seasrulos detonaciurma talRam an impulsurma magniturma velma. dReisaTvis, impulsuri magnituri veli gamoiyeneba rogorc puansoni an matrica Txelkedliani kargi eleqtrogamtarobis mqone masalisagan damzadebuli detalebis tvifvris, mownexvis, gaSlis, kalibrebis da sxva teqnologiuri operaciebis Sesasruleblad. igi warmatebiT cvlis detonaciur teqnologias, rodesac afeTqebis talRa asrulebs puansonis an matricis rols. am ukanasknels aqvs didi upiratesoba praqtikuli gamoyenebis TvalsazrisiT.

Zlieri impulsuri magnituri veliT meqanikur zemoqmedebas adgili aqvs nebismier magnitur-impulsur sistemaSi, romlis blok-sqema naCvenebia naxazze.

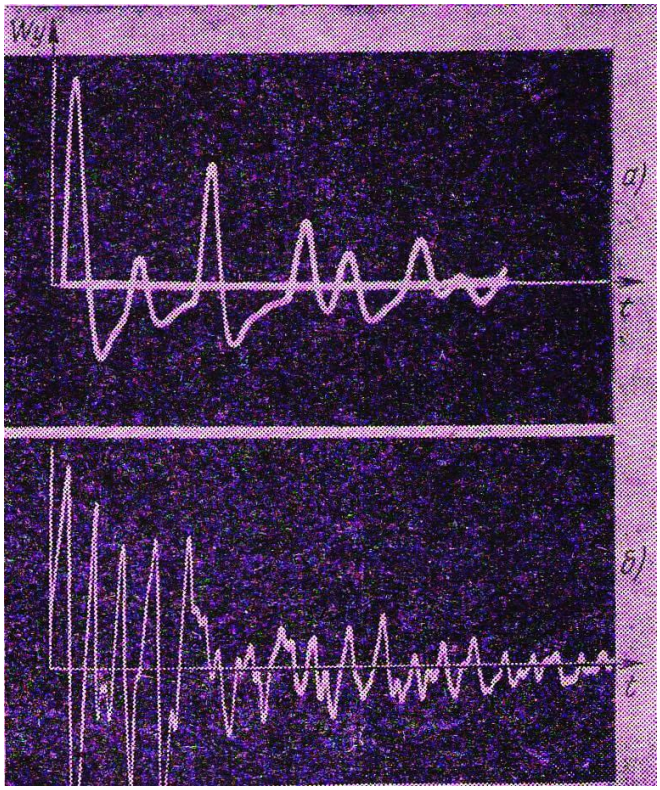


nax. 2.1

nax. 2.1-ze naCvenebia magnitur-impulsuri sistema, romelic Sedgeba:

1. dammuxtveli mowyobilobisagan, romelic waroadgens cvladi denis gammarTvelis asamaRlebeli transformatoriT da ventiliT;
2. impulsuri denis generatorisagan, maRali Zabvis impulsuri kondensatorebis batareiT, ganmmuxtaviT da 3 teqnologiuri kvanZisagan, romelic Seicavs induqtorsa da impulsuri magnituri velis zemoqmedebis obieqts;
4. sistemis marTvis, signalizaciis, dacvisa da blokirebis kvanZi;
5. sainformacio-sazomi sistema, romelic Seicavs mzom gardamsaxebs, analogiur-cifrul gardamsaxebs da gamoTvliTi teqnikis saSualebebs.

magnitur-impulsuri sistema Sedgeba dammuxtavi mowyobilobisgan, romelic warmoadgens cvladi denis gammarTvels asamaRlebeli transformatoriT da ventiliT, impulsuri denis generatorisgan maRali Zabvis mcire induqciurobis mqone impulsuri kondensatorebis batareiT, maRali Zabvis ganmmuxtveliT da sistemis teqnologiuri kvanZiT. es ukanaskneli moicavs induqtors da muSa Reros – sistemis meqanikur talRagamtars. sistema Seicavs agreTve marTvis, signalizaciis, dacvisa da blokirebis kvanZs, sainformacio sazom kompleqss. masSi SeiZleba Sediodes eleqtronul-optikuri gardamqmneli, analogur-cifruli gardamqmnli, sabeWdi mowyobiloba da gamomTvleli manqana. gamosakvlevi obieqti, vTqvaT aCqarebis gamzomi gardamsaxi, Tavsdeba talRagamtaris erT-erT torcze, romelic asrulebs dartymiT aCqarebul moZraobas, gamowveuls talRagamtaris meore torcze impulsuri magnituri velis zemoqmedebiT. talRagamtarSi warmoSobili impulsuri deformaciebi kontroldeba tenzometruli gardamqmneliT. impulsuri denis, deformaciisa da aCqaarebis gamzomi gardamsaxis reaqciis oscilogramebi sxvadasxa SemTxvevisaTvis naCvenebia naxazze [29].



nax. 2.2

nax. 2.2-ze naCvenebia obieqtis aCqarebis a(t) da gardamsaxis reaqciis v(t) osciloGramebi sxvadasxva SemTxvevisas.

talRagamtaris datvirTvis aseTi sqema, rodesac impulsis xangrZlivoba aTeuli mikrowamis rigisaa miuRebelia deformaciis talRis geometriuli dispersiis gamo. Tu movaxdenT cilindruli Reros gverdidan agznebas impulsuri magnituri velis saSualebiT, am SemTxvevaSi impulsuri deformaciis aRgznebis adgili ReroSi maqsimalurad iqneba miaxlovebuli talRagamtaris muSa torsTan, ris gamoc minimumamde dayvaneba dispersiuli movleniT gamowveuli damaxinjebebi. am ideis realizeba SesaZlebelia magnitur-impulsuri teqnologiuri an diagnostikuri daniSnulebis danadgarSi, romlis pirdapiri daniSnulebaa piezoeleqtruli dartymiTi aCqarebis gamzomi gardamsaxis sakuTari sixSireebis gansazRvra [19].

damuSavebulia mZlavri magnitur _ impulsuri sistema, romlis impulsuri denis generatorSi gamoyenebulia ИРТ-2 tipis

ignitronuli ganmmuxtveli. misi nominaluri Zabva da deni Sesabamisad aris 10kv da 100ka, magram mas ar aqvs ventiluri Tviseba, ris gamoc, denis generatori Sesrulda denis watacebis sqemiT damatebiTi ganmmuxtavis gamoyenebiT. sistemaSi gadawyvetilia ZiriTadi da damatebiTi ganmmuxtvelebis anTebis da eleqtronuli oascilografebis gaSvebis procesebis sinqronizaciis amocana. aqac, sistemis sainformacio-sazomi kompleqsi Seicavs impulsuri denebis, deformaciebisa da aCqarebebis gamzom gardamsaxebs, optikur-eleqtronul gardamqmnels an analogur-cifrul gardamqmnels informaciis damuSavebis Sesabamisi sistemiT. konstruqciuli masalebis dinamiuri maxasiaTeblebis gansazRvris dros talRagamtari mzaddeba gamosakvlevi masalisagan, xdeba signalebis erTdrouli registracia oscilografebis saSualebiT. miRebuli Zabvisa da deformaciis, rogorc drois funqciebis oscilogramebis damuSavebiT ganisazRvreba masalis dinamiuri maxasiaTeblebi deformaciis siCqaris mocemuli mniSvnelobis dros.

piezoeleqtruli aCqarebis gamzomi gardamsaxebis Tavisufali rxevebis oscilogramirebis damuSavebis meTodika da gardamsaxis amplitudur-sixSiruli maxasiaTeblis speqtruli meTodiT gansazRvra iZleva srul informacias gardamsaxis struqturis da sakuTari sixSireebis Sesaxeb.

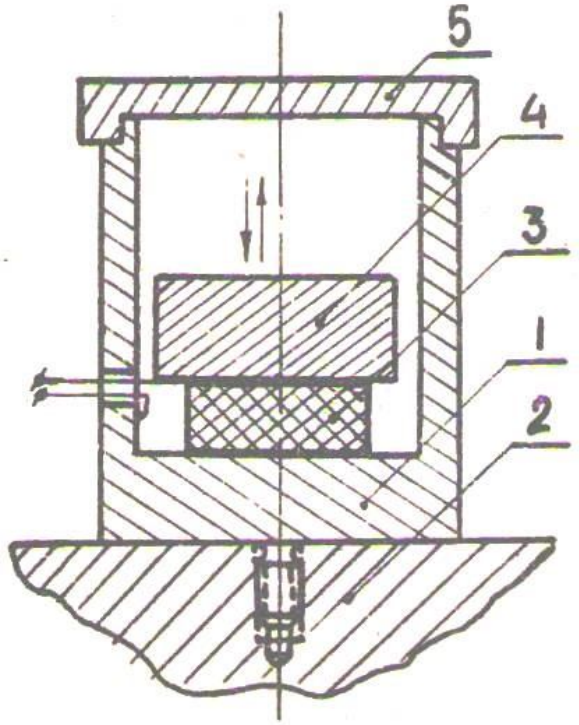
cnobilia, rom magnitur-impulsur diagnostikur danadgarSi energiis dagroveba xdeba kondensatorSi da am energiis ganmuxtva ignitronnuli an vakuumuri ganmmuxtavis saSualebiT induqtorze (teqnologour kvanZze). miuxedavad imisa, rom es ganmmuxtavebi saSualebas iZleva Zlieri denebis komutirebisa da Sesabamisad, teqnologiur kvanZSi Zlieri impulsuri magnituri velebis generirebisa, maTi saSualebiT SeuZlebelia Zalze xanmokle sakvlevi obieqtis aRmgznebi impulsuri zemoqmedebis formireba, vinaidan amuSavebis Semdeg es komutatorebi rCebian CarTul mdgomareobaSi da atareben dens vidre ar moxdeba kondensatorSi dagrovili energiis sruli disipacia, induqtorSi gamavali denis impulss aqvs milevadi sinusoidis forma. am dros ki

Zalzed mniSvnelovania, rom sadiagnostiko obieqtis, aCqarebis piezoeleqtruli gardamsaxis aRmgznebi impulsi iyos Zalian mokle, miaxlovebuli delta impulsTan, romlis speqtraluri simkvrive erTis tolia. mcdeloba aRmgznebi impulsis damoklebisa (denis unipolaruli impulsis generireba) damatebiTi komutatoris gamoyenebiT, arc Tu ise efeqturia Sedegebis dabali ganmeorebadobis an saimedoobis gamo, vinaidan orive ganmmuxtvelis sinqronizacia sakmaod rTuli teqnikuri problemaa da obieqtis aRmgznebi impulsis xangrZlivoba da sidide ar aris stabiluri. yovelive amis gamo, ignitronuli an vakuumuri ganmmuxtvelebi naklebad efeqturia rogorc komutatori magnitur-impulsuri diagnostikuri danadgarebisTvis.

arsebobs agreTve magnitur-impulsuri danadgari, sadac komutatoris rols asrulebs tiristori, romelic gamoirCeva xanmedegobiT, muSaobis stabilurobiT da iZleva unipolaruli impulsuri denis miRebis saSualebas. magram, vinaidan impulsuri tiristorebic ki SezRudulia dasaSvebi denis cvlilebis siCqariT, maTi saSualebiT didi simZlavris komutireba da Sesabamisad, induqtorSi mZlavri unipolaruli impulsis miReba SeuZlebelia [66].

magnitur-impulsuri diagnostikuri danadgaris teqnologiur kvanZSi _ induqtorSi SesaZlebelia miviRoT Zalzed xanmokle da mZlavri impulsi, Tu danadgarSi komutatorad gamoviyenebT reversiulad CarTvad dinistors. rC dinistori ramdenime aseuli kiloamperi denis komutirebis saSualebas iZleva erTeul mikrowamebSi.

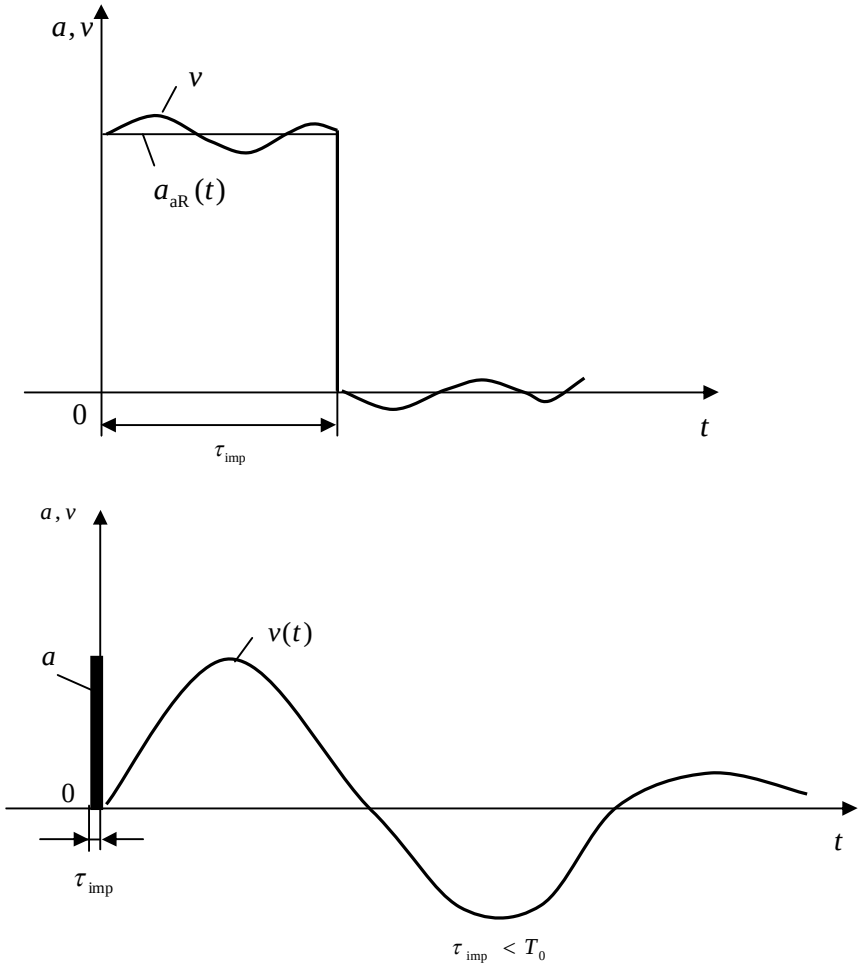
stu-Si aris sankt-peterburgis metrologiis institutis mier aRniSnuli masalebis gamoyenebiT Seqmnili dartymiTi aCqarebis ПИ 93 seriis gamzomi gardamsaxebis gamokvlevebis mdidari gamocdileba [73].



nax. 2.3

1. korpusisagan; 2. gardamsaxi damagrebuli a sakvlev obieqtze weboTi an xraxniT; 3. mgrZnobiare elementi; 4. liTonis wriuli an oTxkuTxa formis tvirTi.

nax. 2.3-ze naCvenebia misi konstruqciuli sqema, romelic Sedgeba korpusisagan 1, mgrZnobiare elementis 3 da wriuli an oTxkuTxa formis tvirTisagan 4 masiT m, gardamsaxi damagrebuli a sakvlev obieqtze 2 weboTi an xraxniT. Nnax. 2.4-ze naCvenebia obieqtis aCqarebis a(t) (gardamsaxisTvis aRgznebis) da gardamsaxis reaqciis v(t) oscilogramebi sxvadasxva SemTxvevisTvis. sakvlevi obieqtis moZraobis parametrebis dadgena xdeba Sesabamisi oscilogramis damuSavebiT.



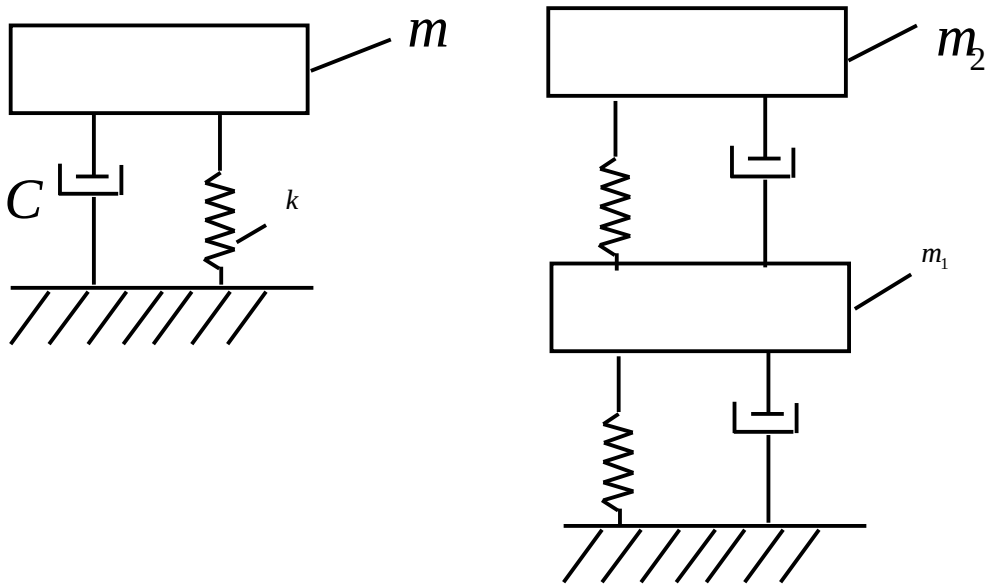
nax. 2.4

nax. 2.4-ze naCvenebia obieqtis aCqarebis a(t) da gardamsaxis reaqciis v(t) oscilogramebi sxvadasxva SemTxvevisTvis.

dinamikuri gamocdebis dros miRebuli informaciis srulfasovani damuSavebisTvis aucilebelia gamoyenebuli gamzomi gardamsaxebis, maT Soris piezoeleqtruli aCqarebis gamzomi gardamsaxis dinamikur maxasiaTebelTa sruli speqtri, rac SeiZleba mopovebuli iqnes TviT gamzomi gardamsaxebis yovelmxrivi gamokvlevebiT maTze xanmokle dartymiTi zemoqmedebis saSualebiT, msgavsad eleqtruli wredebis sixSiruli maxasiaTeblebis kvlevisa impulsuri meTodiT [71].

dartymiTi piezoeleqtruli aCqarebis gamzomi gardamsaxebi warmoadgenen rxeviT sistemebs maRali sakuTari rxeviTi sixSireebiT. mowyobiloba SeiZleba modelirebuli iqnes erTi,

ori an mravalmasian ganawilebul parametrebiani rxeviTi sistemebiT.



nax. 2.5

maTi praqtikuli gamoyenebis dros gazomvis Sedegebis damuSavebisas gazomvis maRali sizustis uzrunvelyofisaTvis saWiroa gvqondes informacia gamzomi gardamsaxebis amplitudursixSiruli maxasiaTeblebis Sesaxeb. es informacia, msgavsad eleqtruli wredebisa, SeiZleba mopovebul iqnes gardamsaxze aCqarebis xanmokle impulsis zemoqmedebiT misi mgrZnobiarobis mimarTulebiT. gardamsaxis aRmgznebi impulsisa da Sesabamisi reaqciis registraciis da maTi Semdgomi damuSavebiT. cxadia, rom maRalsixSiruli gardamsaxis efeqturi aRgznebisaTvis saWiroa aRmgznebi impulsis xangrZlivoba naklebi an Tanazomadi iyos gardamsaxis sakuTari rxevebis periodTan SedarebiT.

piezoeleqtruli aCqarebis gamzomi gardamsaxebis dinamiuri maxasiaTeblebis kvlevisas, gansakuTrebiT maTi arawrfivobis gansazRvrisas saWiroa maTi agzneba impulsuri aCqarebiT, romlis pikuri mniSvneloba aRwevs 10^6 m/wm^2 xangrZlivobiT 10mkwm.

am TvalsazrisiT aqtualuria, Seiqmnas piezoeleqtruli aCqarebis gamzomi gardamsaxis dinamikuri maxasiaTeblebis gamosakvlevi mowyobiloba, romelic saSualebas mogvcems movaxdinoT sakvlevi obieqtis srulyofili diagnostika [70,64].

2.2. piezoeleqtruli gamzomi gardamsaxebis parametrebis gansazRvris meTodebi da saSualebebi

SemoTavazebuli magnitur-impulsuri diagnostikuri daniSnulebis danadgari Seicavs dammuxtav mowyobilobas, mcire induqciurobis mqone impulsuri kondensatorebis batareas, induqtors, romelSic moTavsebulia liTonis talRagamtari zed damagrebuli aCqarebis piezoeleqtruli gardamsaxi, komutators reversiulad CarTvadi dinistoris sqemiT. danadgari muSaobs Semdegnairad: komutatorze impulsis miwodebisas gaiReba dinistori da xdeba kondensatorebis batareis gadacla induqtorze. denis pirveli naxevartalRis gavlis Semdeg dinistori iketeba da aRar atarebs denis ukutalRas. induqtorSi moTavsebuli talRagamtari ganicdis impulsur meqanikur zemoqmedebas da masze damagrebuli sakvlevi obieqti aRigzneba erTjeradi unipolaruli impulsiT. impulsis xangrZlivoba stabiluria da ar aris damokidebuli gare faqtorebze. impulsuri zemoqmedebis sidide da xangrZlivoba damokidebulia mxolod damuxtvis Zabvis sidideze da ganmuxtvis wredis parametrebze.

reversiulad CarTvadi dinistoris gamoyeneba, msgavsad impulsuri tiristorebiT awyobili komutatorisa, saSualebas iZleva induqtorSi gavataroT praqtikulad unipolaruli impulsuri deni, rac gansakuTrebiT mniSvnelovania piezoeleqtruli aCqarebis gamzomi gardamsaxebis diagnostirebis dros, rodesac gazomvebis sizuste didad aris damokidebuli sakvlev obieqtze Sesavali Zalovani zemoqmedebis xangrZlivobaze. gamosacdeli obieqtis metrologiuri maxasiaTeblebi _ struqtura, sakuTari rxevebis sixSire, demfirebis koeficienti, mgrZnobiaroba, arawrfivoba ganisazRvreba mowyobilobis reaqciisa da impulsuri zemoqmedebis speqtralur simkvriveTa fardobiT. es fardoba martivdeba, rodesac impulsuri zemoqmedeba Zalze xanmoklea da uaxlovdeba delta funqcias, rac niSnavs, rom gamosacdeli obieqtis gadacemis funqciisa da reaqciis speqtraluri simkvriveebi praqtikulad Tanxvdenili funqciebia. am dros, obieqtis reaqciis

speqtraluri simkvrive praqtikulad igivea, rac obieqtis kompleqsuri sixSiruli maxasiaTebeli da obieqtis diagnostikuri kvleva midis mis impulsur zemoqmedebaze reaqciis analizTan.

sadiagnostiko obieqtis, piezoeleqtruli aCqarebis gamzomi gardamsaxis Zalzed xanmokle impulsur aRgznebaze reaqciis speqtraluri simkvrivis analiziT SesaZlebelia garadamsaxis struqturis dadgena, amplitudur – sixSiruli, sakuTari sixSireebis, demfirebis, arawrfivobis da sxva metrologiuri maxasiaTeblebis maRali sizustiT gansazRvra.

sadiagnostiko gamzomi gardamsaxi warmoadgens eleqtromeqanikur rxeviT sistemas, romelic aRigzneba impulsuri aCqarebiT. diferencialuri gantoleba, romelzec daiyvaneba aCqarebis gamzomi gardamsaxis gantolebaTa sistema, iqneba

$$b_n \frac{d^n \varepsilon}{dt^n} + b_{n-1} \frac{d^{n-1} \varepsilon}{dt^{n-1}} + \cdots b_1 \frac{d\varepsilon}{dt} + b_0 \varepsilon = f(t),$$

sadac $b_n, b_{n-1}, ...b_o$ koeficientebi ganisazRvreba rxeviTi sistemis parametrebiT; $f(t)$_aRgznebis funqcia ganisazRvreba impulsuri aCqarebiT da rxeviTi sistemis parametrebiT; ε_gamzomi gardamsaxis reaqcia impulsur zemoqmedebaze.

Ggamzomi gardamsaxis sakuTari rxevebis sixSireebi ganisazRvreba amplitudur-sixSiruli maxasiaTebliT, romelic warmoadgens gardamsaxis gadacemis funqciis speqtraluri simkvrivis moduls. gardamsaxis gadacemis funqciis speqtraluri simkvrive

$$S(j\omega) = \frac{S_\varepsilon(j\omega)}{S_f(j\omega)} = \frac{1}{b_n(j\omega)^n + b_{n-1}(j\omega)^{n-1} + ..b_1 j\omega + b_0},$$

sadac $S_f(j\omega)$ da $S_\varepsilon(j\omega)$ _ gardamsaxis aRgznebisa da reaqciis speqtraluri simkvriveebi Sesabamisad.

aCqarebis gamzomi gardamsaxis, rogorc meqanikuri rxeviTi sistemis, kompleqsuri sixSiruli maxasiaTebeli SeiZleba gansazRvrul iqnes, rogorc

$$S(j\omega) = \frac{S_\varepsilon(j\omega)}{S_a(j\omega)},$$

sadac $S_a(j\omega)$ aris gardamsaxis aRmgznebi dartymiTi aCqarebis speqtraluri simkvrive. gamzomi gardamsaxis aRgznebisas delta an masTan miaxloebul impulsuri funqciiT, romlis speqtraluri simkvrive erTis tolia. gardamsaxis kompleqsuri sixSiruli maxasiaTebeli ganisazRvreba, rogorc reaqciis speqtraluri simkvrive

$$S(j\omega) = S_{\varepsilon}(j\omega).$$

am SemTxvevaSi gardamsaxis reaqciaSi faqtiurad ar aris iZulebiTi mdgeneli. gardamsaxi asrulebs Tavisufal rxevebs nulovani sawyisi gadaadgilebiT da sawyisi siCqariT. rxeviTi sistemis kompleqsuri sixSiruli maxasiaTebeli aris sistemis Tavisufali rxevebis kompleqsuri simkvrive. rodesac gamzomi gardamsaxis reaqcia Seicavs iZulebiT mdgenels, sakmarisia vicodeT dartymiTi aCqarebis impulsis xangrZlivoba τ_0 da gardamsaxis reaqcias movaciloT Sesabamisi sawyisi ubani, maSin

$$S_1(j\omega) = \exp(-j\omega\tau_0)\cdot S(j\omega).$$

am tolobidan Cans, rom speqtralur simkvriveebs S da S_1 aqvT erTnairi modulebi, ase rom gardamsaxis reaqciis darCenili nawilis speqtri warmoadgens gardamsaxis amplitudur-sixSirul maxasiaTebels [59,61].

meTodikis Tanaxmad reaqciis darCenili nawili gadayvanili unda iqnes diskretul formaSi $\Delta t = (\tau-\tau_0)/2n$ bijiT, sadac aris gardamsaxis reaqciis xangrZlivoba da $2n$ - amonakrebTa ricxvi.

gardamsaxis amplitudur-sixSiruli maxasiaTebeli gamoiTvleba Semdegi formuliT:

$$S(2\pi f_k) = \sqrt{I_{1k}^2 + I_{2k}^2},$$

sadac

$$I_{1k} = \int_{\tau_0}^{\tau} \xi(t)\cos(2\pi f_k t)dt, \qquad I_{2k}\int_{\tau_0}^{\tau} \xi(t)\sin(2\pi f_k t)dt.$$

aq f_k sixSire Rebulobs diskretul mniSvnelobebs Δf bijiT f_{min} – f_{max} sixSirul intervalSi, sadac $f_{min} = 1/\tau$ da $f_{max} = 1/2\Delta t$.

amgvarad, $S(2\pi f_k)$ saWiroa ganisazRvros mocemuli formulidan, sadac

$$f_1=f_{min},$$

$$f_2=\Delta f+f_{min},$$

$$f_3=2\Delta f+f_{min},$$

$$f_i=(i-1)\Delta f+f_{min}=f_{max}.$$

cxadia, (39) formulaSi k icvleba $1<k<i$ diapazonSi da

$$i=1+\frac{f_{max}-f_{min}}{\Delta f}.$$

integralebi I_{1k} da I_{2k} ganisazRvreba simpsonis cnobili formulebiT, rac advilad eqvemdebareba kompiuterul gamoTvlebs.

Zalzed mniSvnelovania, rom sadiagnostiko obieqtis piezoeleqtruli dartymiTi aCqarebis gamzomi gardamsaxis impulsuri aRgzneba iyos Zalian xanmokle, miaxloebuli delta impulsTan, romlis speqtraluri simkvrive erTis tolia. am dros obieqtis reaqciis speqtraluri simkvrive praqtikulad igivea, rac obieqtis kompleqsuri sixSiruli maxasiaTebeli da obieqtis diagnostikuri kvleva midis mis impulsur zemoqmedebaze reaqciis analizTan.

sadiagnostiko obieqtis, piezoeleqtruli gamzomi gardamsaxis Zalzed xanmokle impulsur aRgznebaze reaqciis speqtraluri simkvrivis analiziT SesaZlebelia garadamsaxis struqturis dadgena, amplitudur-sixSiruli, sakuTari sixSireebis, demfirebis, arawrfivobis da sxva metrologiuri maxasiaTeblebis maRali sizustiT gansazRvra [62].

Tavi III. naxevargamtaruli komutatorebi

3.1. tradiciuli komutaciuri procesi naxevargamtarul xelsawyoebSi

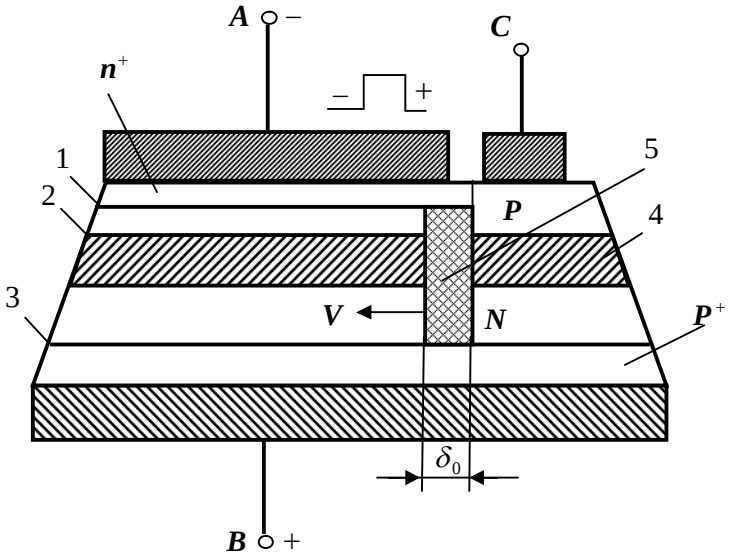
rogorc zemoT iyo aRniSnuli, didi simZlavreebis komutacia dRemde xorcieldeboda airganmuxtvis xelsawyoebiT da maT ganviTarebaSi miRweuli warmatebebis Sedegad Seiqmna mravali unikaluri danadgari, romlebic gamoyenebulia teqnikuri fizikisa da teqnologiebis sferoebSi. magram, airganmuxtvis xelsawyoebs aqvT maTSi mimdinare procesebidan gamomdinare, mTeli rigi uaryofiTi mxareebi: amuSavebis arastabiluroba, romelic arTulebs sinqronizacias rTul sistemebSi; gamoyenebis mokle vada, ganpirobebuli eleqtrodebis swrafi daSliT. garda amisa, airganmuxtvis xelsawyoebi naklebad saimedonia, rTuli eqspluataciaSi da mgrZnobiareni gare zemoqmedebaze.

airganmuxtvis xelsawyoebis aRniSnuli uaryofiTi mxareebis gamo xdeba maTi Canacvleba mZlavri naxevargamtariani xelsawyoebiT _ tiristorebiTa da tranzistorebiT. savaraudod, am xelsawyoebs unda moecvaT mZlavri impulsuri maRalsixSiruli teqnika, magram es ar moxda mizeziT, romelsac aqvs principuli xasiaTi.

didi simZlavreebis komutacia nebismieri tipis naxevargamtariani xelsawyoTi xdeba am xelsawyos garkveuli nawilis gamtarobis mkveTri zrdiT, romelsac aqvs sawyis stadiaze Zalzed didi winaRoba da ablokirebs naxevargamtarul xelsawyoze modebul Zabvas. es nawili warmoadgens Zlieri eleqtruli veliT muxtis matareblebisagan mTlianad dacliil moculobiTi muxtis ubans (ukuwanacvlebuli p-n gadasasvlelis moculobiTi muxtis ubani). am raionis gamtarobis mkveTri zrda SeiZleba moxdes misi eleqtronul-xvreluri plazmiT Sevsebis gziT. magram, naxevargamtaruli xelsawyos xvedriTi (erTeul zedapirze mosuli) komutirebuli simZlavre SezRudulia plazmaSi muxtis matareblebis dabali Zvradobisa da koncentraciis, agreTve, arc Tu maRali muSa temperaturis gamo. Sedegad, mniSvnelovani simZlavreebis

komutirebisTvis saWiroa xelsawyoSi Seiqmnas didi muSa moculobis gamtari ubani. plazmaSi muxtis matareblebis difuziuri sigrZis SedarebiT mcire mniSvnelobebi ar iZleva saSualebas gavzardoT mocululoba eleqtrodebs Soris manZilis zrdiT, rogorc es xdeba airganmuxtvis xelsawyoebSi. rCeba erTaderTi gza _ dengamtari arxis ganivkveTis gazrda. amgvarad, naxevargamtaruli xelsawyos zRvruli komutaciuri maxasiaTeblebi damokidebulia imaze, Tu ramdenad swrafad formirdeba didi winaRobis mqone ubnis adgilas didi diametris mqone mokle mdgradi plazmuri arxebi.

Tanamedrove mZlavr naxevargamtarul xelsawyoebSi (bipolarul tranzistorebsa da tiristorebSi) dengamtari arxebi formirdeba emiteruli fenebidan inJeqcirebuli muxtis matareblebiT. tiristoris SemTxvevaSi, sadac oTxi fenaa sami p-n gadasasvlviT ori kiduri (emiteruli) gadasasvlvlebi CarTulia gamtari mimarTulebiT, xolo centraluri (koleqtoruli) axdens xelsawyoze modebuli Zabvis blokirebas.

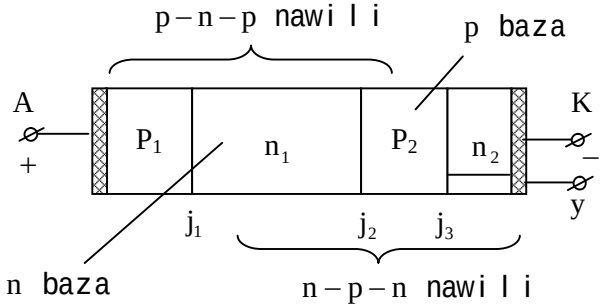


Nnax. 3.1

nax. 3.1-ze naCvenebia oTxSriani p^+Npn^+ tiristoris struqtura AB _ Zalovani wredi; AC _ marTvis wredi; 1, 3 _ emiteruli $p-n$ gadasvlebi; 2 _ koleqtoruli $p-n$ gadasvla; 4 _ koleqtoris mocululobiTi muxtis are; 5 _ plazmuri arxi.

tiristoris oTxfenian $p-n-p-n$ struqturaSi p da n ubnebSi muxtis ZiriTadi matareblebis gansxvavebuli koncentraciis gamo, TiToeul $p-n$ gadasvlaSi gadis difuziis deni. am dros warmoqmnili moculoBiTi muxtebi qmnian velebs, romlebic xels uSlian muxtebis ZiriTadi matareblebis Tavisufal difuzias da iwveven araZiriTadi matareblebis denebs (dreifis denebs). Sedegad xelsawyoSi myardeba wonasworoba da masSi deni aRar gadis [65].

anodsa da kaTods Soris gareSe pirdapiri Zabvis modebiT ganapira emiteruli gadasvlebi j_1 da j_3 wainacvlebs pirdapiri mimarTulebiT (marcxnidan marjvniv) da centraluri koleqtoruli gadasvla j_2 sawinaaRmdego mimarTulebiT



nax. 3.2 ukuwanacvlebuli $p-n$ gadasvlis moculobiTi muxtis zona aRmoCndeba mTlianad daclili muxtis matareblebisagan da blokavs xelsawyoze modebul Zabvas.

aRniSnuli zonis gamtarobis mkveTri zrda da, Sesabamisad, xelsawyos gadarTva SesaZlebelia zonis SevsebiT kargi eleqtruli gamtarobis mqone eleqtronul-xvreluri plazmiT.

xelsawyos gadarTvisas am gadasasvlvlis moculobiTi muxtis ubani unda Seivsos plazmiT, romlis inicireba xdeba impulsuri denis gatarebiT emiter-bazis wredSi sabazo Txeli fenis gaswvriv. am fenis didi winaRobis gamo eleqtronebis inJeqcia emiteruli p-n gadasvliT lokalizdeba viwro arxSi emiteri-bazis sazRvris gaswvriv. tiristorebSi CarTvis mdgomareoba vrceldeba Zalzed dabali siCqariT (0.1–0.005 mm/mkwm), tranzistorebSi ki arxis sigane ar aris damokidebuli droze. amis gamo,

aRniSnul xelsawyoebSi SeuZlebelia didi farTis dengamtari arxebis miReba da Sesabamisad komutaciis Cveulebrivi principis gamoyenebiT maT ar SeuZliaT konkurencia gauwion airganmuxtvis xelsawyoebs swrafi komutaciis pirobebSi simZlavreTa mega da gigavatian diapazonSi. Tanamedrove mZlavri magnitur-impulsuri sistemebi saWiroeben naxevargamtarul komutatorebs, romlebic SesZleben aRniSnul diapazonSi funqcionirebas da amave dros eqnebaT naxevargamtaruli xelsawyoebis tradiciuli upiratesobebi: didi sagarantio vada, maRali saimedoba, mdgradoba gareSe zemoqmedebebisadmi da myisieri mzaoba muSa reJimSi Sesasvlelad.

3.2 komutatori impulsur tiristorebze

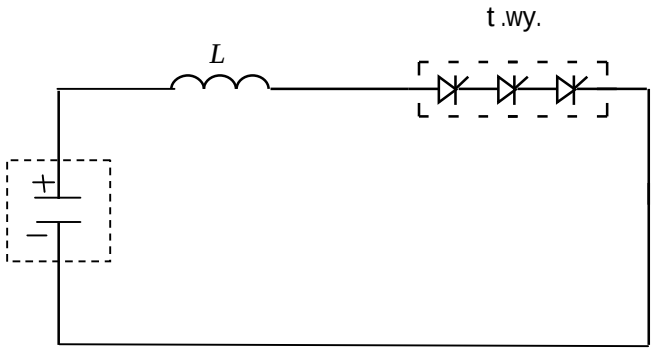
stu-Si Cvens mier damuSavda dartymiTi aCqarebis sazomi ПИ-93 tipis maRalsixSiruli piezoeleqtruli gamzomi gardamsaxebis sadiagnostiko danadgari K16-05, romelic warmoadgens magnitur-impulsur mowyobilobas, romelic muSa organoSi (meqanikur talRagamtarze) anviTarebs aCqarebis impulss xangrZlivobiT 10-50mkwm da pikuri mniSvnelobiT 10^3m/wm^2-mde. am mizniT mowyobiloba Seicavs impulsuri denis generators, romelSic naxevradgamtariani komutatoris saSualebiT iqmneba naxevarsinusoidis formis impulsuri deni 3ka pikuri mniSvnelobiT 3kv Zabvamde damuxtuli kondensatorebis batareis induqtorze ganmuxtviT [50,51].

komutatori Sesrulebulia koaqsialuri kabelis principiT da cal mxares aRWurvilia induqciuri SuntiT impulsuri denis registraciisaTvis. komutatoris WiqaSi Casmulia mimdevrobiT SeerTebuli oTxi TU-3000 tipis mecxre klasis tiristori. komutatoris maqsimaluri Zabva SeiZleba iyos 3600v da amgvarad, misi gamoyenebis koeficienti Seadgens

$$k = \frac{V_n}{V_m} = \frac{3000}{3600} = 0.83,$$

rac qmnis garkveul rezervs muSa Zabvis TvalsazrisiT. tiristorebi SerCeuli iyo aTi xelsawyoiani partiidan. am mizniT

tiristorebi SeerTebuli iyo mimdevrobiT nax. 3.3-ze naCvenebi sqemis mixedviT.



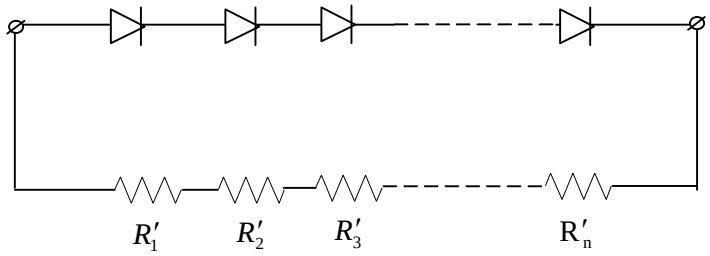
nax. 3.3

cxrilSi naCvenebia wyobilze modebuli 4500 v Zabvis ganawileba tiristorebze.

cxrili #3.1. 4500v Zabvis ganawileba tiristorebze

eqsperimenti	Zabva tiristorebze, V									
	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10
#1	700	200	500	350	900	250	200	600	700	100
#2	850				900			850	900	

cxrilis monacemebis mixedviT partiidan SeirCa T1, T5, T8 da T9 tiristorebi, romlebzec dayenebuli iqna gamaTanabrebeli rezistorebi da kondensatorebi naCvenebi sqemis mixedviT.



nax. 3.4

$$\frac{R_1^{'} \cdot R_1}{R_1^{'} + R_1} = \frac{R_2 \cdot R_2^{'}}{R_2 + R_2^{'}} = \frac{R_3 \cdot R_3^{'}}{R_3 + R_3^{'}} = \cdots = \frac{R_n \cdot R_n^{'}}{R_n + R_n^{'}} \quad (3.1),$$

sadac $R_1, R_2, R_3 \ldots R_n$ diodebis ukuwinaRobebia, $R_1^{'}, R_2^{'}, R_3^{'} \ldots R_n^{'}$ – rezistoris winaRobebia.

(3.1) pirobis dakmayofileba saWiroa, rogorc mowyobilobis damzadebis stadiaze, aseve misi eqspluataciis periodSi, rodesac mimdinareobs izolaciis cveTisa da daberebis intensiuri

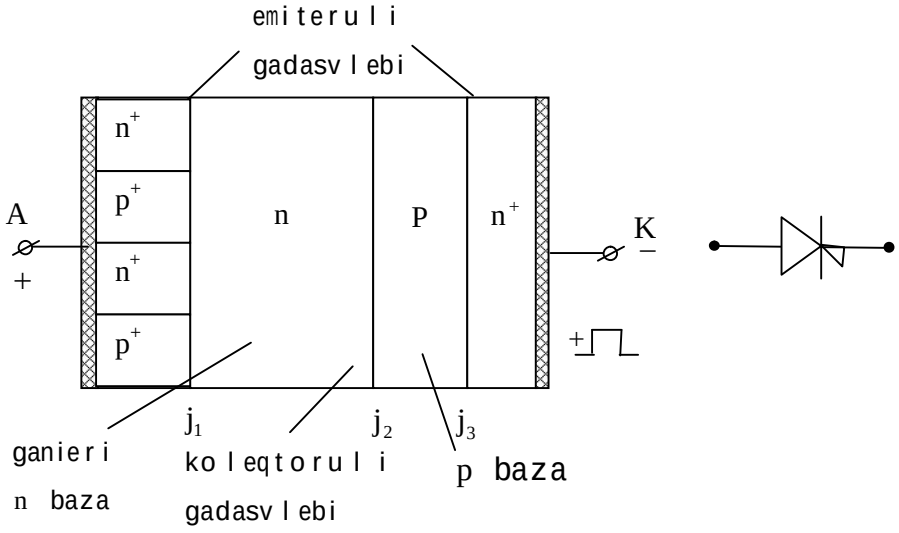
procesi da xelsawyos rigis periodul i diagnostireba. damatebi-Ti rezistoris SerCevisas praqtikul ad aris $\frac{R}{R'} = 5 \div 10$.

tiristorebze 3500v Zabvis ganawilebis suraTi mocemul ia cxrilSi.

CarTvis mdgomareobis gavrcelebis dabal i siCqaris gamo, saukeTeso Zalovan impulsur TU-3000 tiristorebSic ki sakomutacio denis cvlilebis siCqare ar unda aRematebodes 800a/mkwm-s da Sedegad SeuZlebel ia aseTi tiristorebiT aRWurvil i mikro an nanowamebis diapazonSi muSaobisTvis gankuTvnil i mZlavri magnitur-impulsuri sistemebis Seqmna [48,49].

3.3. komutacia samarTavi plazmuri feniT

samarTavi plazmuri feniT naxevradgamtariani xelsawyoebis komutaciis principi damuSavda a.f. iofes sax. fizika-teeqnikis institutSi. am meTodis gamoyenebis dros magal iTad, tiristorSi raime xerxiT xdeba eleqtronul-xvreluri plazmis erTgvarovani fenis formireba koleqtorul i p-n gadasasvlel is sibrtyeSi.



nax. 3.5

xelsawyoSi *n* da *p* zonebis, yvela *p* da *n* struqtura Zlier (zRvrul ad) aris legirebul i da aRiniSneba p^+ da n^+ _ iT.

xelsawyoze modebuli Zabva mocemuli polarobiT aRniSnuli sibrtyidan erTgvarovnad gadaadgileben xvrelebs p ubanSi da eleqtronebs _ n ubanSi. muxtis es matareblebi, romlebic Ziri-Tadebia p da n ubnebisaTvis, amcireben ra ganapira (emiteruli) p-n gadasvlebis potencialur bariers, axdenen muxtebis araZiriTadi matareblebis inJeqcias Sesabamis bazisur ubnebSi. tiristoris samarTavi eleqtrodi Caenacvleba erTgvarovani (mTeli sibrtyis gaswvriv) plazmuri feniT. Sedegad formirdeba plazmuri dengamtari arxi, romlis ganivkveTis farTi tolia siliciumis firfitis farTis. cnobilia, plazmuri dengamtari arxis formirebis sxvadasxva meTodi: a) koleqtoruli p-n gadasasvlelis impulsuri zvaviseburi garRveva. b) dartymiTi ionizacia mZlavr zemaRal sixSirul (mzs) velSi. g) mZlavri impulsuri kogerentuli da arakogerentuli sinaTliT ionizacia. gansakuTrebiT moxerxebuli da efeqturi aRmoCnda e.w. reversiul-inJeqciuri marTva, romlis drosac marTavi plazmuri fena iqmneba xelsawyoze modebuli Zabvis polarobis xanmokle cvlilebiT. am meTodis safuZvelze Seiqmna ori tipis xelsawyo: reversiulad-CarTvadi dinistori da reversiulad-marTvadi tranzistori [1].

xelsawyoze xanmokle ukuZabvis modebisas (reversirebisas), tranzistoruli elementis $n^+ - p$ emiteruli gadasvla inacvlebs ukumimarTulebiT da gairRveva, xolo $p - n$ dioduri Semadgeneli inacvlebs pirdapiri mimarTulebiT da elementSi gadis impulsuri deni. xdeba plazmis inJeqcia n sivrceSi.

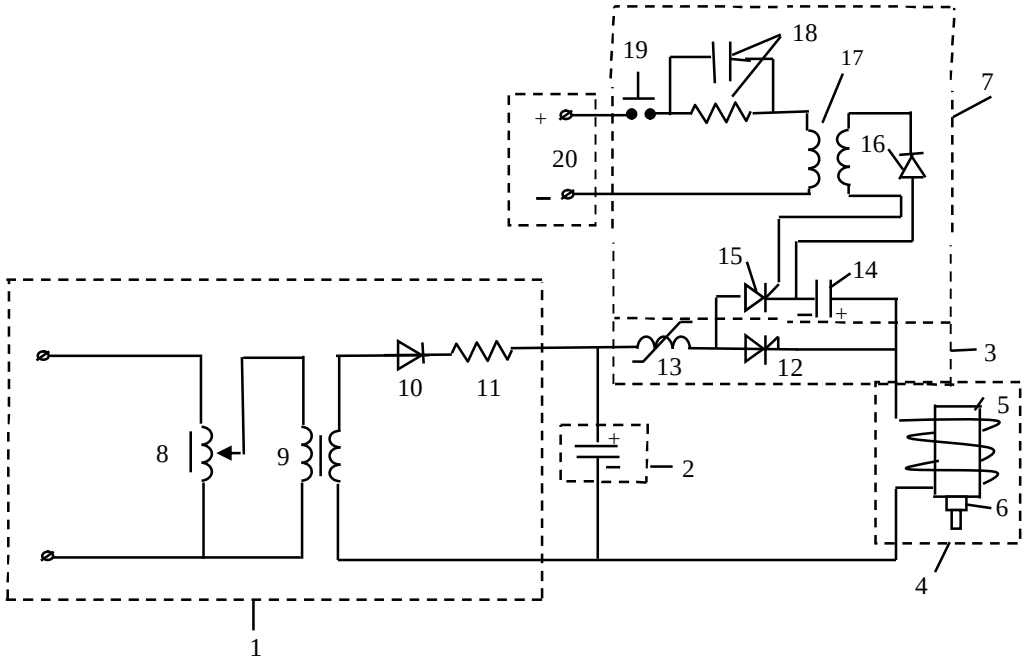
impulsuri denis damTavrebisas xdeba xelsawyoze modebuli Zabvis xelaxali cvlileba _ pirdapiri mimarTulebis Zabvis modeba. am dros plazmidan eleqtronebi da xvrelebi inacvleben n da p bazebSi, xdeba muxtis araZiriTadi matareblebis inJeqcia emiteruli fenidan da xelsawyos CarTva erTdroulad mTel farTze. amis Sedegia xelsawyoTi didi simZlavris komutirebis SesaZlebloba [47].

3.4. reversiulad CarTvadi dinistori

rogorc avRniSneT, stu-Si Cvens mier damuSavebulia dartymiTi aCqarebis sazomi ПИ-93 tipis maRalsixSiruli piezoeleqtruli gamzomi gardamsaxebis sadiagnostiko danadgari K16-05, romelic miekuTvneba magnitur-impulsur mowyobilobebs, da SeiZleba gamoyenebul iqnes aCqarebis piezoeleqtruli gardamqmnelebis kontrolisa da diagnostikisaTvis, maTi sakuTari rxevebis sixSiris dasadgenad Zlieri impulsuri magnituri velis zemoqmedebiT sakvlev obieqtze dartymiTi aCqarebis aRgznebis gziT. SemoTavazebuli diagnostikuri magnitur-impulsuri danadgaris teqnikuri Sedegia gamomavali darTymiTi impulsis stabilurobis amaRleba, misi xangrZlivobis Semcireba da amplitudis gazrda, razedac miRebuli gvaqvs saqarTvelos patenti P 5374.

teqnikuri Sedegi miiRweva imiT, rom warmodgenili magnitur-impulsuri danadgari Seicavs dammuxtav mowyobilobas, mierTebuls kondensatorebis batareasTan, induqtors, komutators da marTvis mowyobilobas; kondensatoris batarea komutatoris gavliT mierTebulia marTvis blokTan da induqtorTan; induqtori aRWurvilia talRasatariT, romelic Sesrulebulia liTonis Reros saxiT; komutatoris sakomutacio elementad gamoyenebulia reversiulad CarTvadi dinistori.

SemoTavazebuli magnitur-impulsuri danadgari Seicavs dammuxtav mowyobilobas 1, kondensatorebis batareas 2, komutators 3, induqtors 4 masSi moTavsebuli liTonis talRasatariT 5, romelzec amagreben sakvlev obiqts 6 (aCqarebis piezoeleqtrul gardamqmnels), marTvis mowyobilobas 7; dammuxtavi mowyobiloba 1 Seicavs avtotransformators 8, amwev transformators 9, gammarTvel diods 10 da balastur rezistors 11; komutatori 3 Seicavs reversiulad-CarTvad dinistors 12 da droselS 13; marTvis mowyobiloba 7 Seicavs kondensators 14, marTvad tiristors 15, diods 16, impulsur transformators 17, RC-wreds 18, gamSveb Rilaks 19. marTvis blokis kveba xorcieldeba mudmivi denis wyarodan 20.



nax. 3.6. magnitur-impulsuri danadgaris principuli eleqtruli sqema

magnitur-impulsuri danadgari muSaobs Semdegnairad:

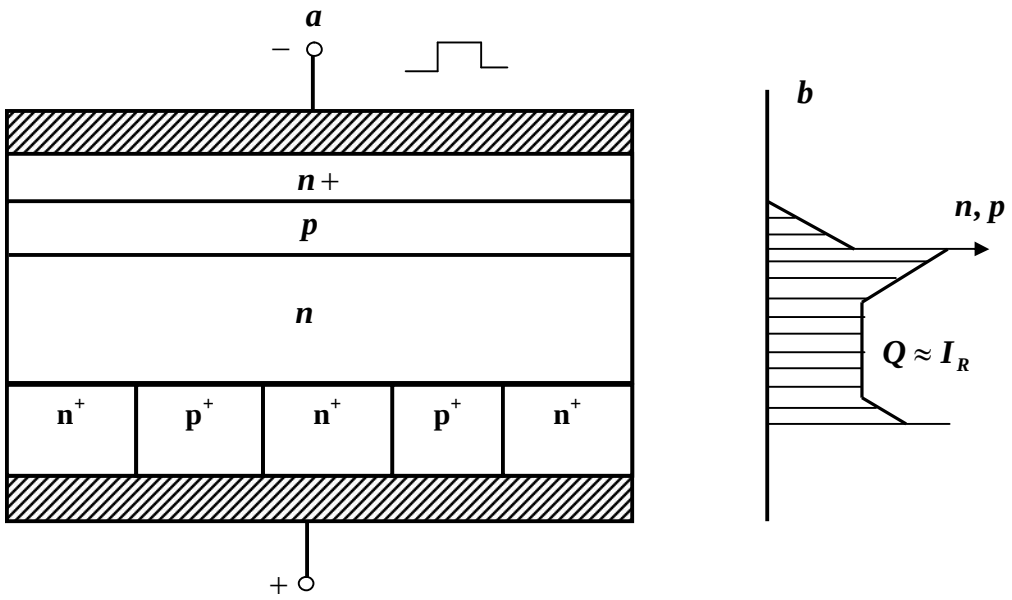
avtotransformatori 8 irTveba cvladi denis qselSi, xolo komutatoris marTvis mowyobiloba 7 - mudmivi denis wredSi. avtotransformatoris 8 da amwevi transformatoris 9 meSveobiT gammarTveli diodis 10 da balasturi rezistoris 11 gavliT xdeba kondensatorebis batareis 2 damuxtva sasurvel Zabvamde. gamSveb Rilakze 19 daWerisas impulsuri transformatoris 17 pirvelad gragnilSi gaivlis RC-wredis 18 kondensatoris damuxtvis deni. am transformatoris meoreul gragnilSi aRiZvreba impulsuri deni, romelsac diodis 16 meSveobiT eZleva unipolaruli forma. es deni aRebs marTvad tiristors 15. xdeba kondensatoris 14 ganmuxtva reversiulad CarTvad dinistorze 12 da am ukanaskneli s gaReba.

komutatoris 3 gaRebis Semdeg xdeba kondensatorebis batareis 2 ganmuxtva induqtorze 4, romelSic gaivlis mZlavri erTjeradi unipolaruli xanmokle denis impulsi. es impulsi Sesabamisi impulsuri magnituri velis saSualebiT liTonis talRasatarSi 5 aRZravs dartymiT aCqarebas, romelic vrceldeba ra

talRasatarSi 5, aRagznebs masze damagrebul sakvlev obieqts 6 (aCqarebis piezoeleqtrul gardamqmnels). droseli 13 zRudavs kondensatorebis batareidan 2 kondensatorisaken 14 gamaval dens reversiulad CarTvadi dinistoris 12 gaRebamde [19].

amrigad, SemoTavazebuli magnitur-impulsuri danadgari iZleva induqtorSi xanmokle, mZlavri erTjeradi unipolaruli impulsuri denis miRebis saSualebas, romlis xangrZlivoba da amplituda stabiluria da ar aris damokidebuli gare faqtorebze.

konstruqciulad reversiulad CarTvadi dinistori Sedgeba urTierTmonacvle ramodenime aTeuli aTasi tiristoruli da tranzistoruli elementebisagan damaxasiaTebeli zomiT, romelic naklebia, vidre xelsawyos ganieri n bazis sisqe. am elementebs aqvT saerTo centraluri (koleqtoruli) gadasasvleli, romelic ablokirebs xelsawyoze modebul Zabvas mocemuli polarobiT. am elementebs saerTo aqvT agreTve zeda $n^+ - p$ emiteruli gadasasvleli, romelic warmoqmnilia zRvrulad Zlier legirebuli n^+ feniT da sakmaod Zlier legirebuli (10^{18}sm^{-3}) p feniT. xelsawyoze modebuli Zabvis polarobis xanmokle Secvlisas (reversirebisas) tranzistoruli elementebis dabal Zabviani $n^+ - p$ emiteri waenacvleba Caketvis mimarTulebiT da gairRveva, xolo $p - n^+$ dioduri mdgeneli – pirdapiri mimarTulebiT. elementSi miedineba impulsuri gamSvi deni, romelsac Tan sdevs plazmis Sefrqveva n sferoSi, romelic saerToa tranzistoruli da maT gverdiT ganlagebuli tiristoruli elementebisTvis.



nax. 3.7. rCd-s naxevargamtaruli struqtura (*a*) da plazmis SemosazRvris gaJRenTvisas (*b*).

plazmis svetis forma nax. 3.7-is sibrtyeSi axlosaa trapeciasTan, romlis qveda fuZe tolia tranzistoruli elementis zomis, xolo zeda fuZe – daaxloebiT *n* bazis sisqis. vinaidan tiristoruli elementis sigane naklebia am sisqeze, koleqtorTan plazmuri svetebi erTmaneTs gadafaraven da warmoiqmneba sakmaod erTgvarovani plazmuri fena. impulsuri gamSvi denis Sewyvetis Semdeg xdeba xelsawyoze modebuli Zabvis polarobis ganmeorebiTi Secvla. am dros eleqtronebi da xvrelebi koleqtoris mimdebare plazmuri fenidan wainacvleben *n* da *p* bazebSi Sesabamisad, iwveven muxtis araZiriTadi matareblebis Sefrqvevas (inJeqcias) emiteruli fenebidan da xelsawyos CarTvas erTdroulad mTeli zedapiris gaswvriv. igulisxmeba, rom gadairTveba mxolod tiristoruli elementebi. vinaidan tranzistoruli elementebis sigane gacilebiT naklebia *n* bazis sisqeze da masSi matareblebis difuziur sigrZeze, am elementebis *n* bazebic Seivseba plazmiT da monawileoben denis gatarebaSi, e.i. xdeba muSa farTis srulad gamoyeneba [4].

gamSvi da ZiriTadi denebis gzis Tanxvdenlobis gamo, aucilebeli xdeba Zalovani da marTvis denebis wredebis

ganmxoloeba gamSvi denis gavlis dros, rac xorcieldeba gajerebadi gularis mqone droseliT nax. 3.16-is mixedviT.

mZlavri reversiulad CarTvadi dinistoris SemTxvevaSi, rodesac dinistori blokavs ramodenime kilovolt Zabvas da komutacias ukeTebs aseulobiT kiloamper dens erTeul mikrowamebis ganmavlobaSi, gamSvi denis impulsis xangrZlivoba Seadgens ramdenime mikrowams. xelsawyoSi denis simkvrive Seadgens $0.5-2*10^4$ a/sm^2, eleqtruli velis daZabuloba n bazaSi Seadgens $E \approx 10^2-10^3$ v/sm, xolo matareblebis saSualo koncentracia ar aRemateba 10^{15} sm^{-3}. amave dros, Zalovani denis gatarebisas 20-30 mikrowamis ganmavlobaSi plazmis koncentracia ar aWarbebs 10^{16} sm^{-3}.

gaSvebis procesis bolos tiristorul da tranzistorul elementebSi formirebulia plazmuri fenebi. Semdgom, ganmamxoloebeli droselis gulara iJRinTeba da droseli kargavs Zalovani da marTvis wredebis ganmamxoloeblis funqcias. wanacvleba xelsawyoze kvlav icvlis niSans da iwyeba tiristoruli elementebis CarTva [44].

3.5. dinistoruli komutatoris parametrebi

reversiulad CarTvadi dinistoruli komutatori msgavsad Cveulebrivi dinistoruli komutatorisa, konstruqciuli zomebis garda, xasiaTdeba mTeli rigi parametrebiT: nominaluri Zabva, mimdevrobiT SeerTebuli dinistorebis raodenoba, denis maqsimaluri mniSvneloba, denis cvlilebis maqsimaluri dasaSvebi siCqare, Zabvis cvlilebis siCqare, gamSvi denis impulsis pikuri mniSvneloba, impulsis forma da xangrZlivoba, komutatoris induqciuroba, tevadoba da talRuri winaRoba.

komutatoris maqsimaluri Zabva ganisazRvreba V_m gamoyenebis obieqtis teqnologiuri daniSnulebidan, romelic gansazRvravs gansamuxti kondensatorebis batareaSi dagrovil energias W. aqedan

$$V_m = \sqrt{\frac{2W}{C}},$$

sadac C kondensatorebis batareis tevadobaa.

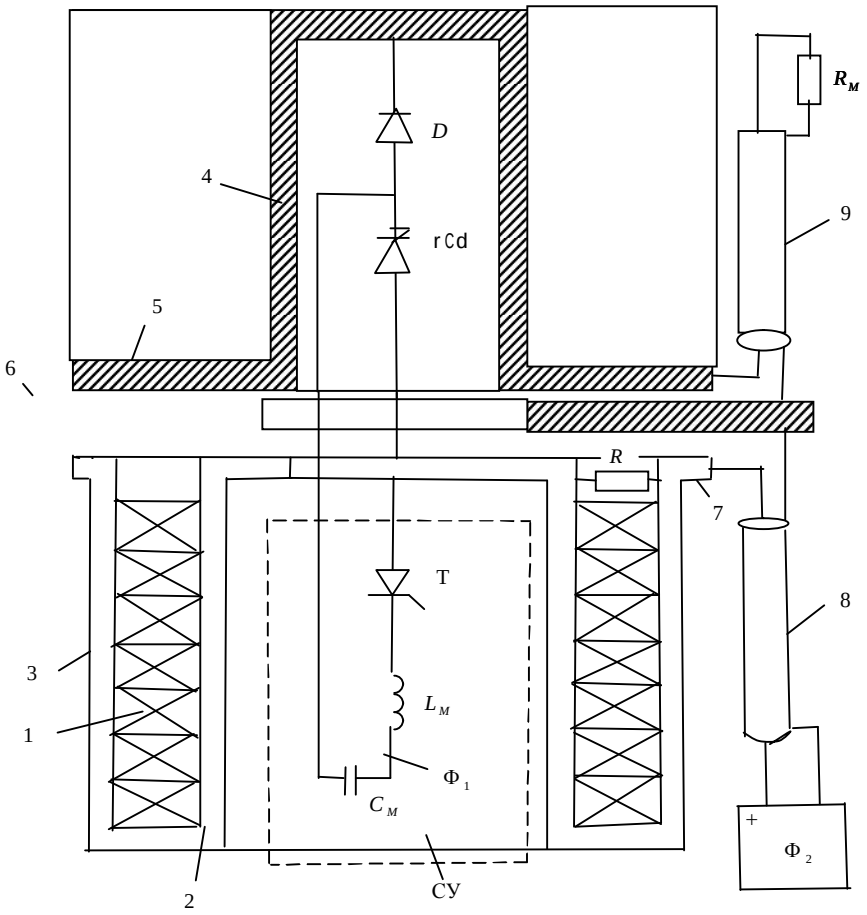
meores mxriv, komutatoris nominaluri Zabva unda akmayofilebdes pirobas

$$V_m = knV_d,$$

sadac n – mimdevrobiT SeerTebuli dinistorebis raodenoba, k= 0.8 – 0.95 maragis koeficienti, V_d _ dinistoris nominaluri Zabva.

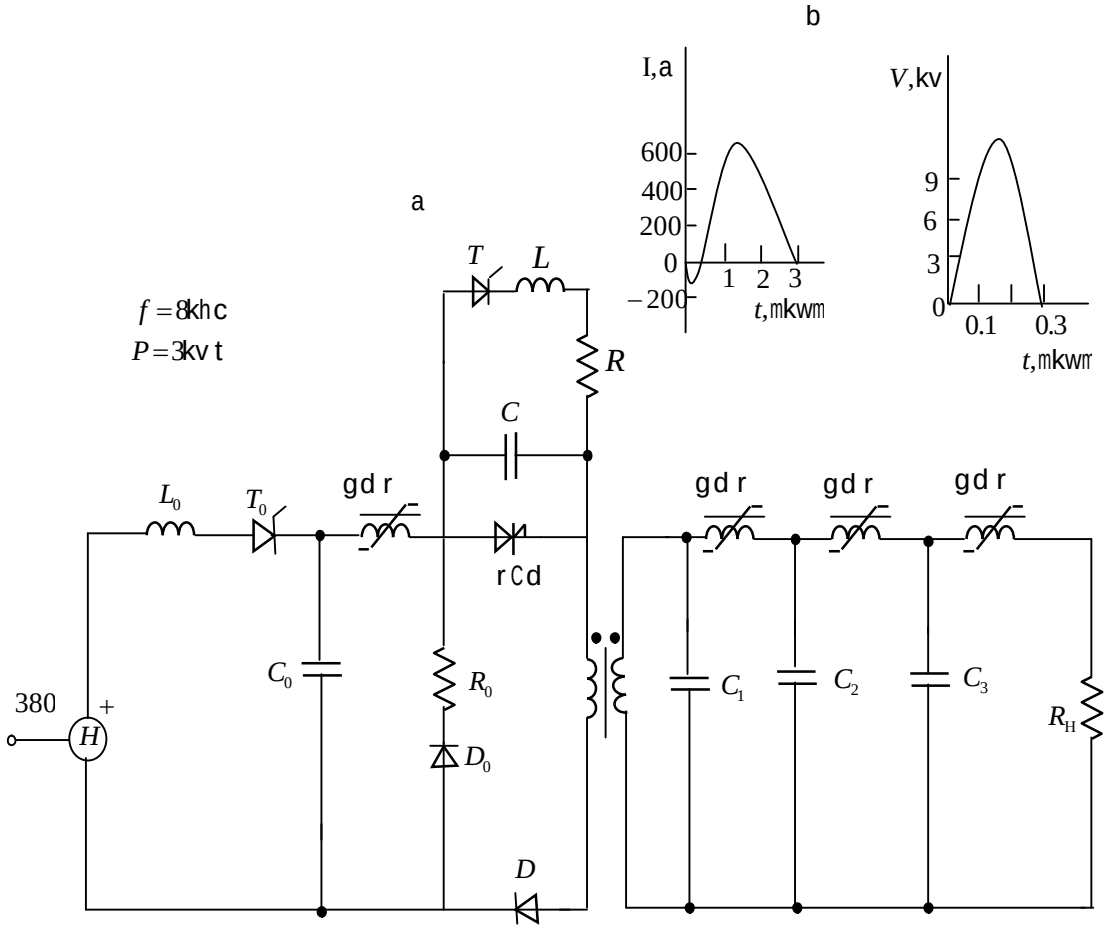
praqtikuli mosazrebebidan gamomdinare dinistoruli komutatorisTvis miviRoT, rom maragis koeficienti k = 0.9.

komutatoris induqciurobis, tevadobisa da talRuri winaRobis dasadgenaT ganvixiloT naxazz 3.8-ze naCvenebi konstruqcia, romelSic realizebulia koaqsialuri kabelis mowyobis principi [5].



nax. 3.8. mZlavri rC dinistoriani komutatoris konstruqcia.

1. droselis gulara; 2. spilenZis mili; 3. koaqsialuri dengamtari; 4, 7 _denmomxsneli; 8, 9 _koaqsialuri kabelebi. droselis gulara 1 Seqmnilia permaloisgan, romelic Camocmulia spilenZis milze 2, da garemoculia uku koaqsaluri sadeniT 4. maRali Zabvis bloki, masTan mimdevrobiT CarTuli rCd da diodi D, aseve maTac aqvT ukusadeni 4, romelic Sesrulebulia koaqsialurad ganlagebuli latunis detalebisgan. marTvis sistema ganlagebulia 2 milis SigniT, R_H datvirTvasa da $\Phi_2$maformireblis mierTeba xdeba koaqsialuri kabelebiT 8, 9, romlebic magrdebian dengamtarebis perimetrze. periodul reJimSi aseT komutators SeuZlia 300ka denis gadarTva 100mkwm marTkuTxa impulsis xangrZlivobisas da 7,5kv Zabvisas, xolo xelsawyos ormxrivi wyliT gacivebisas 100hc sixSireze akomutirebs 50ka dens 30mkwm marTkuTxa impulsis xangrZlivobisas.



nax. 3.9

nax. 3.9-ze naCvenebia maRalsixSiruli rC dinistoriani generatoris sqema (a); gamomavali da Semavali impulsis forma (b).

n raodenobis, b sisqis dinistorob abebis wyoba gansazRvravs komutatorSi gamavali denis pirdapiri sadenis sigrZes $l = nb$, romlis ganivkveTi aris dinistoris liTonis sakontaqto firfitis farTi diametriT d_1. rogorc naxazidan Cans komutatori Casmulia spilenZis milSi Siga diametriT d_2. es ukanaskneli warmoadgens komutatoris denisaTvis ukusadens. amgvarad, komutatoris induqciuroba iqneba

$$L = \frac{\mu_0}{2\pi} \ln \frac{d_2}{d_1} nb.$$

dinistoris erTi abis tevadoba iqneba

$$C_1 = \frac{\varepsilon_0 2\pi b}{\ln \frac{d_2}{d_1}}$$

xolo mimdevrobiT SeerTebuli n dinistoris tevadoba

$$C = \frac{C_1}{n} = \frac{\varepsilon_0 2\pi b}{n \ln \frac{d_2}{d_1}}.$$

komutatoris talRuri winaRoba

$$Z = \sqrt{\frac{L}{C}} = \frac{n \ln \frac{d_2}{d_1}}{2\pi} \sqrt{\frac{\mu_0}{\varepsilon_0}}.$$

gamovTvaloT aRniSnuli parametrebi, komutatorisaTvis, sadac n=5, d_1=50mm, d_2=60mm, b=15mm.

gaangariSebuli sidideebi:

$$L = \frac{\mu_0}{2\pi} \ln \frac{d_2}{d_1} nb = \frac{4\pi \cdot 10^{-7}}{2\pi} \ln \frac{60 \cdot 10^{-3}}{50 \cdot 10^{-3}} \cdot 5 \cdot 15 \cdot 10^{-3} = 30 \cdot 10^{-10} \text{ hn.}$$

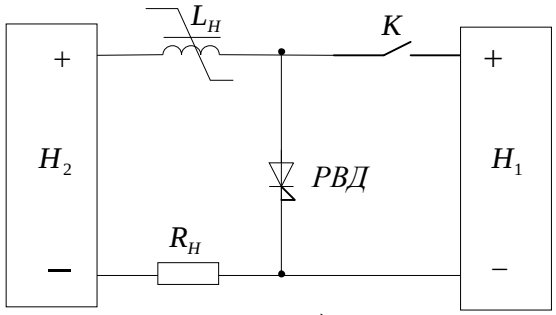
$$C_1 = \frac{\varepsilon_0 2\pi b}{\ln \frac{d_2}{d_1}} = \frac{8.85 \cdot 10^{-12}}{\ln \frac{60 \cdot 10^{-3}}{50 \cdot 10^{-3}}} \cdot 2\pi \cdot 15 \cdot 10^{-3} = 416.8 \cdot 10^{-14} \text{ f.}$$

$$C = \frac{C_1}{n} = \frac{\varepsilon_0 2\pi b}{n \ln \frac{d_2}{d_1}} = \frac{416.8 \cdot 10^{-14}}{5} = 83.4 \cdot 10^{-14} \text{ f}.$$

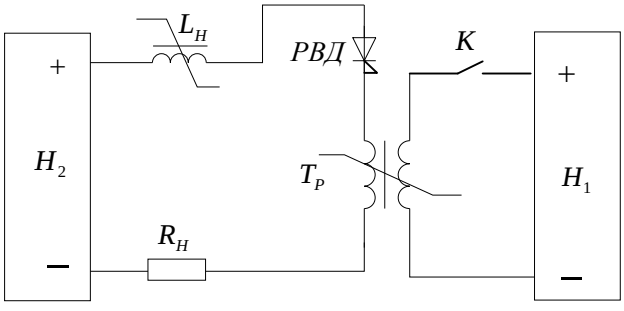
$$Z = \sqrt{\frac{L}{C}} = \frac{n \ln \frac{d_2}{d_1}}{2\pi} \sqrt{\frac{\mu_0}{\varepsilon_0}} = \sqrt{\frac{30 \cdot 10^{-10}}{83.4 \cdot 10^{-14}}} = 0.4 \cdot 10^2 = 40 \text{ omi}.$$

rogorc zemoT avRniSneT, magnitur-impulsuri diagnostikuri danadgaris teqnologiur kvanZSi _ induqtorSi SesaZlebelia miviRoT Zalzed xanmokle da mZlavri impulsi, Tu danadgarSi komutatorad gamoviyenebT reversiulad CarTvad dinistors. rC dinistori iZleva ramdenime aseuli kiloamperi denis komutirebis saSualebas erTeul mikrowamebSi [6].

76mm diametris reversiulad CarTvadi $KPD-25-170$ tipis dinistori saSualebas iZleva 200ka pikuri mniSvnelobis 30mkwm xangrZlivobis monoimpulsuri denis komutirebis $\frac{di}{dt} = 30$ ka/mkwm denis cvlilebis siCqariT. amisaTvis, saWiroa dinistorSi ukumimarTulebiT 2 mkwm xangrZlivobis 1 ka maqsimaluri mniSvnelobis impulsuri denis gatareba.



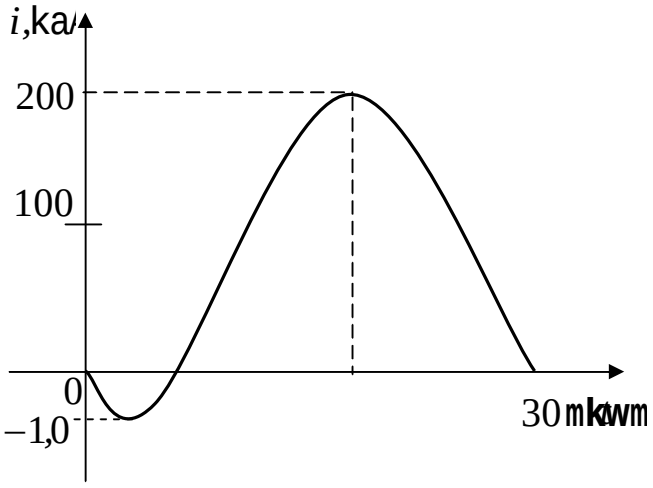
а)



б)

nax. 3.10

nax. 3.10-ze naCvenebia Zlieri impulsuri denis generatoris ori varianti, sadac komutatorad gamoyenebulia reversiulad-CarTvadi dinistori. dinistoris datvirTvas SeiZleba warmoadgendes induqtori, romelic SeiZleba iyos magnitur-impulsuri sistemis teqnologiuri kvanZi. maT Soris gansxvaveba mdgomareobs dinistorisa da misi marTvis ganmxoloebis xerxebSi. am miznisaTvis a) variantSi gamoyenebulia arawrfivi droseli, xolo b) variantSi impulsuri transformatori gaJRenTvadi gulariT (piktransformatoriT). orive variantSi gamoyenebulia impulsuri denis generatoris damgrovebeli H_2 kondensatorebis batareis saxiT, kondensatori H_1 da KCamrTveli dinistorSi ukudenis gasatareblad.



nax. 3.11

nax. 3.11-ze naCvenebia dinistorSi gamavali impulsuri denis oscilograma, romelic saSualebas iZleva dadgindes dinistoris datvirTvis denis parametrebi.

cxrili #3.2. reversiulad CarTvadi-dinistorebis ZiriTadi parametrebi

tipebi	**ukuZabva** V_{DRM}	**ukudeni** I_{DRM}	**pirdapiri deni** I_{TM}
	v	ma	ka
$PBD123-16$	3000	15	16
$PBD123-22$	2000	15	22
$PBD143-40$	3000	50	40
$PBD143-55$	3000	50	55
$PBD153-50$	3000	70	50
$PBD153-80$	3000	70	80
$PBD163-120$	3000	100	120
$PBD163-200$	2000	100	200
$PBD173-200$	3000	150	200
$PBD193-500$	500	300	500

cxrilSi mocemulia reversiulad CarTvadi dinistorebis ZiriTadi parametrebi. aseve moyvanilia rCd axali Taobis gamocdis Sedegebi siliciumis firfitis sxvadasxva diametriT.

cxrili #3.3. rCd axali Taobis gamocdis Sedegebi siliciumis firfitis sxvadasxva diametriT

diametri rCd, mm	**zRvruli deni** I_{pm} **, ka**	**muSa deni** I_{pm} **, ka**
63	250	200
63	150	120
76	380	305
76	240	180
100	540*	500

cxrilSi SedarebisTvis naCvenebia reversiulad CarTvadi dinistorebis pirveli Taobis elementebis (76mm diametriT) gamocdebis Sedegebi, romelic gamoyenebulia komutatorebSi. naTlad Cans, rom sakomutacio unari reversiulad CarTvadi dinistorebis axali TaobisTvis mniSvnelovnad aRemateba rC dinistorebis pirveli Taobis SesaZleblobebs da metia imave diametris tiristoris sakomutacio SesaZleblobebze [7].

axali reversiulad CarTvadi dinistorebi damzadebulia ori variantiT: standartuli liTon-keramikuli korpusiT da ukorpusod, romelsac gaaCnia zemoqmedebisgan damcavi periferiis are (nax. 3.12).

nax. 3.12 komutaciis axal principebze dayrdnobiT Seqmnili xelsawyoebi.

dinistori korpusiT gamoiyeneba monoimpulsur reJimSi, romelic gulisxmobs naxevargamtari xelsawyoebis iZulebiT gacivebas da gamagrileblebis gamoyenebas dinistoris orive mxares. ukorpuso dinistorebi SeerTebulia mimdevrobiT maRalvoltiani wyobiT, romelic ganTavsebulia erT kompaqtur korpusSi. aseTi wyobis eqspluatacia SeiZleba mxolod monoimpulsur reJimSi.

komutatoris muSa Zabva Cveulebriv aRemateba reversiulad CarTvadi dinistoris mablokirebel erTeulovan Zabvas ($U_{BO} \leq$ 2400v), amitom komutatorSi gamoyenebulia reversiulad CarTvadi dinistoris ramdenime elementi, romlebic erTmaneTTan SeerTebulia mimdevrobiT. elementebis ricxvi wyobaSi damokidebulia

komutatoris muSa Zabvaze, amitom naxevargamtaruli komutatorebis damuSavebis teqnikuri problema, upirveles yovlisa, mdgomareobs rC dinistorebis ramdenime mimdevrobiTi optimaluri wyobis konstruirebaSi. Catarebulia mTeli rigi specialuri gamokvlevebi (iseTi, rogoricaa optimaluri masalebis SerCeva rC dinistoris kargi kontaqtebis uzrunvelsayofad), romlebic saSualebas iZleva uzrunvelyos dabali da stabiluri gardamavali eleqtruli da siTburi winaRobebi rC dinistorebs Soris, rac iZleva xangrZliv garantias da komutatoris muSaobis saimedoobas. damuSavebulia, specialuri kompiuteruli SerCevis meTodika reversiulad CarTvadi dinistorebis mimdevrobiTi gawyobisTvis. amasTan elementebSi specialurad kontroldeba gaJonvis denebi da mablokirebeli volt-amperuli maxasiaTeblis stabiluroba. am meTodikam saSualeba misca gamoericxaT Zavbis gamyofebi, romlebic aTanabreben statikur Zabvas wyobis TiToeul elementze da maSasadame, gaamartiva komutatoris konstruqcia, daaxloebiT 1.5-jer Seamcira misi gabaritebi da Rirebuleba. nax. 3.12-ze naCvenebia komutatoris tipebi, romlis daniSnulebaa xangrZlivi muSaoba monoimpulsur reJimSi. es myarsxeulovani ventili akomutirebs 300ka impulsur dens, romelic grZeldeba 0.5mkwm da gamoiyeneba lazerul mowyobilobaSi. misi korpusi Seicavs rCd-s 76mm diametris elements da mablokirebel 2.4kv Zabvis mowyobilobas. aseTi konstruqciisas miiRweva Zalian maRali kuTri komutirebadi simZlavris maCvenebeli komutatoris erTeulovan farTobze. igi tolia 2.5×10^6 vt/sm^2.

maT safuZvelze damuSavda axali Taobis reversiulad CarTvadi dinistorebi da komutatorebi, romelTa saSualebiTac miiRweva kuTri komutirebadi simZlavris rekorduli maCvenebeli komutatoris erTeulovan farTobze. komutatorebi muSaoben rogorc monoimpulsur, aseve sixSirul reJimSi da gamoiyenebian farTo diapazonis impulsur energetikaSi [10].

3.6. rCd-s CarTvis procesis ganxilva

aRwerili fizikuri procesebis Sesabamisad, gaJRenTvis procesi xasiaTdeba plazmis ormagi inJeqciis xarjze, maRalomian bazur ***n*** SreSi. ganvixiloT es procesi dawvrilebiT.

Sesasvlelze gamSvi denis eleqtrodebis geometriuli SeTavsebiT da rCd muSaobisTvis principialurad aucilebelia Zalovan marTvis wredSi aRiZras gamSvi impulsuri deni. ZiriTadad, es procesi xorcieldeba gajerebuli droselis gularas dros. mZlavri rC dinistorisTvis, romlebic blokaven maRal Zabvas atareben aseulobiT kiloamper komutaciis dens (denis simkvrive 0.5-2*10^4a/sm^2) mikrowamis diapazonSi, gaSvebis procesis xangrZlivoba aris 1-2mkwm. am dros n- bazis are SedarebiT ar aris didi (E ~ 10^2-10^3v/sm), xolo saSualo koncentracia ar aWarbebs $10^{15}$$sm^3$. ZiriTadi ganmuxtvis denis gasvlis dros oscilogramebidan gamomdinare plazmis saSualo koncentracia 23-30mkwm ganmavlobaSi ver aswrebs gazrdas $10^{16}$$sm^{-3}$-mde. amasTan erTad, xelsawyoSi Seyvanili muxtebis raodenoba maRalia: gaSvebis dros muxtebi aRwevs 10^{-4}kul/sm^2, xolo Semdeg etapze komutirebuli denis sidide izrdeba 1-2 rigiT. es metyvelebs plazmis arastacionaluri ganawilebis mkveTr araerTgvarovnebaze, romelic mimarTulia kaTodidan anodisken. naTlad Cans, rom koncentrirebuli muxtis ZiriTadi nawili mimarTulia koleqtoruli gadasvlis Txeli fenebisa da anoduri emiterisken. am Sefasebebidan gamomdinareobs, rom mikrowamis diapazonisTvis n bazis sisqis ganvladoba modulaciis ZiriTad meqanizmSi warmoadgens bipolarul dreifs, romelic ar arRvevs moculobis neitralurobas. amasTan erTad, dreifis eleqtronebis da n- bazaSi xvrelebis siCqarem SeiZleba miaRwios 10^6sm/wm, anu gamosvlis dro moTavsebulia aTeulobiT nanowamis diapazonSi. amitom n- bazis dreiful SualedSi rekombinacia TvalaCinoa, romelic SegviZlia ise miviRoT mxedvelobaSi, rogorc gadamtanebis sicocxlis dro, romelic Seadgens aTeulobiT mikrowams. aseTi daSvebebiT gantoleba,

romelic gansazRvravs plazmis bipolarul dreifs, SeiZleba gamoisaxos Semdegnairad:

$$\frac{\partial P}{\partial t} = -\frac{bN_d J_{(t)}}{q[(b+1)P + bN_d]^2} \cdot \frac{\partial P}{\partial x} \quad ,$$

sadac $P_{(x,t)}$- aris gadaWarbebuli plazmis koncentracia; N_d- aris legirebuli n-bazis koncentracia; $b = \mu_n / \mu_P$ -aris damokidebuleba eleqtronebsa da xvrelebs Soris sust velebSi; $J_{(t)}$- aris denis simkvrive, romelic gaedineba plazmaSi.

plazmur SreebSi, sadac denis gadamtanebis koncetracia maRalia, emiteris areSi denis gadatanis process aqvs difuziuri xasiaTi. ZiriTad zemoqmedebas rCd-s procesis gadarTvisas, p-bazaSi asrulebs arastacionaluri difuzia, radganac zustad is gansazRvravs kaToduri Semdgenis n^+-p-n tranzistoruli gadasasvlelis, Sesabamisad, tiristoruli struqturis regenirebuli ukukavSiris intensivobasac. p - bazaSi inJeqciuri procesi, SeiZleba aRweril iyos tranzistoris difuziur TeoriaSi.

difuziuri procesebi n - bazaSi moqmedenen maTi gamtarobis modulaciebSi da ama Tu im xarisxSi zegavlenas axdenen Zabvaze. Tumca, mikrowamis xangrZlivobis impulsebisTvis am difuziuri Sreebis sisqe mcirea dreifuli intervalis sigrZesTan SedarebiT. miaxloebiT dinamikaSi isini SeiZleba aRweril iqnas sruli damuxtvis terminebiT, xolo difuziis modulaciis procesSi mcire sacavebi ganvladobis dros maRalomur fenebSi SeiZleba Sefasebuli iyos dreifuli sigrZis efeqturi intervalis Semoyvanis gziT:

$$\omega_{ef} = \omega_n - 2\delta L_{(t)},$$

romelic mcirdeba drois gavlasTan erTad:

$$\delta L_{(t)} \cong \sqrt{Dt_{ef}} \ ,$$

sadac $t_{ef} = (t^{-1} + \tau_P^{-1})^{-1}$ _ aris difuziuri plazmuri fenis gafarToebis efeqturi dro; t _aris mimdinare dro. τ_P _aris denis Warbi

gadamtanebis sicocxlis dro; D _aris ambipoluri difuziis koeficienti.

Sefasebebi gviCvenebs, rom rC dinistoris impedansi (sruli winaRoba), Zlieri gaSvebis dros SesamCnevad mcirea Sida wredebis impendansTan SedarebiT, da gardamavali reJimebis gamoTvla SeiZleba Catardes denis generatoris reJimisaTvis, romelic moewodeba Sida wredidan.

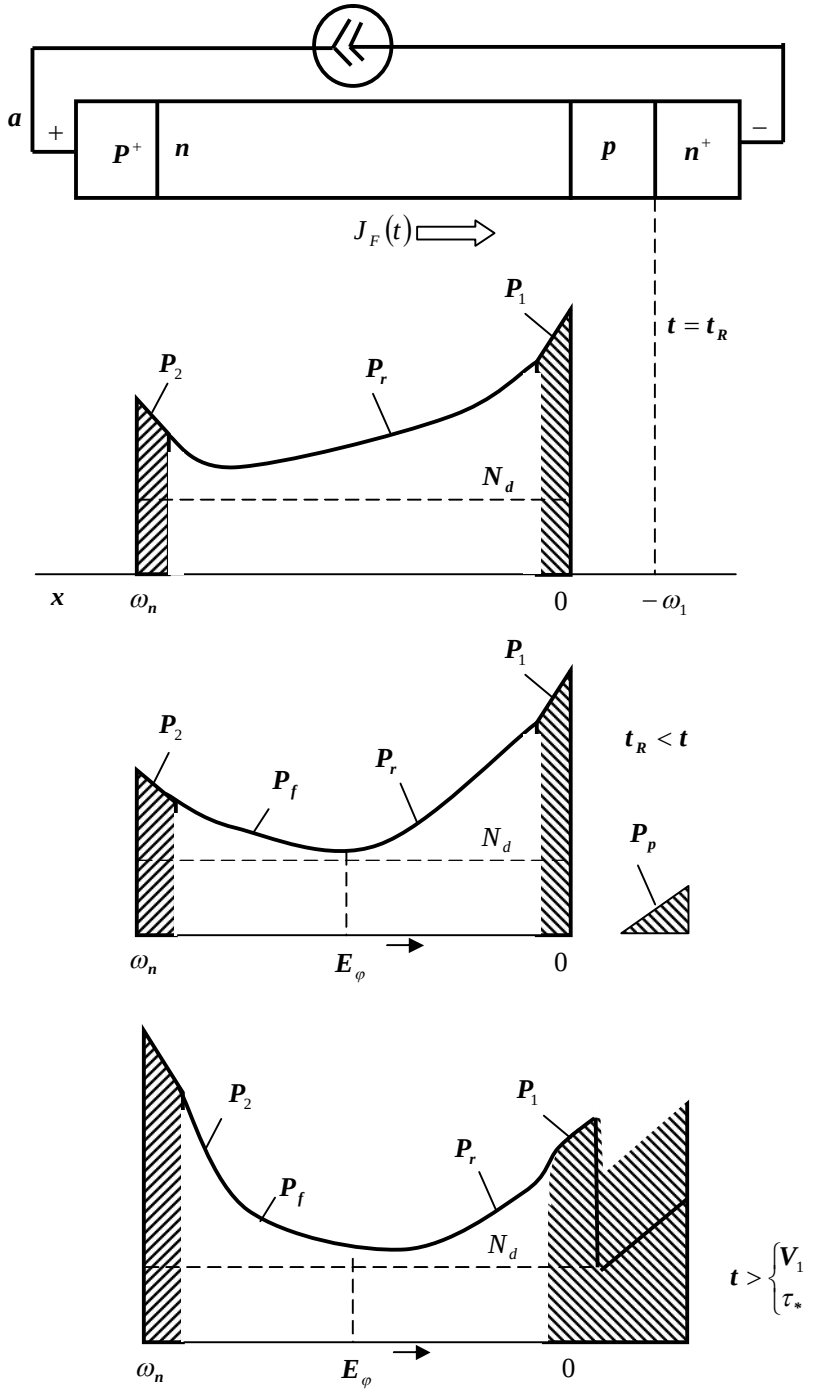
sawyis mdgomareobaSi diodi CarTulia uku mimarTulebiT da blokavs U_0 sawyis Zabvas centraluri $p-n$ gadasvlis struqturis moculobiTi muxtis SriT. am Sris muxti Q damokidebulia U_0 sawyis Zabvaze da Seadgens donorebis sruli muxtis nawilebs $Q_n = qN_d\omega_n$, romlis sidide aris 0,1 mkkul/sm^2.

gaJRenTvis procesSi wanacvlebis Zabvis modebis Semdeg $t=0$ momentSi n- bazis sakuTari eleqtronebis gadanacvlebisas p-Sris mimarTulebiT, xdeba moculobiTi muxtis Sris ganmuxtva. gaJRenTvis sruli muxti Q_R >> Q_{O3} da ganmuxtvis dro $t_c << t_R$. xvrelebis inJeqcia iwyeba $t >> t_c \sim 0$ dros diodis p- emiteris areSi, sadac Tavidan warmoiqmneba plazmis P_1 Txeli Sre denis gadamtanebis maRali koncentraciiT. p-emiteris sazRvarze eleqtronuli deni ar arsebobs, xolo parcialuri velis eleqtronuli komponenti gawonasworebulia Semxvedri difuziiT. velis arseboba n-bazaSi iwvevs xvrelebis dayovnebas difuziuri plazmuri Sridan n^+-emiteris (P_r Sris) mimarTulebiT. garkveuli drois Semdeg n^+-emiteris midamoSi warmoiqmneba meore difuziuri Sre P_2.

gaJRenTvis procesis dasrulebisas tranzistorul elementSi formirdeba plazmuri Sreebis ganawileba. Sreebis aseTive ganawileba warmoiSveba axlos ganlagebul tiristorul elementebzec, naxazi 3.13. amitom ganmamxoloebeli droselis gulara gajerdeba da droseli Sewyvets dayofas Zalovan da mmarTvel wredSi. wanacvlebis Zabva xelsawyoze kvlav icvlis

mimarTulebas da iwyeba tiristoruli elementebis CarTvis procesi. polarobis wanacvlebis Zabvis $U_F > 0$ modebis momentSi CamrTavi tiristoruli elementebis n-bazaSi arsebobs gaJRenTvis Q_R muxti. es muxti ganawilebulia P_1 da P_2 difuziuri Sreebis da P_r dreifuli bipolaruli talRis gaswvriv Zlieri I_F denis impulsis gatarebisas, P_2 Sre ivseba plazmiT P_1 da P_r SreebSi gadanawilebuli savele eleqtronebis maragis da tiristoris p^+-emiteris xvrelebis inJeqciis xarjze. P_1-Sre xvrelebs gascems reversiulad CarTvadi dinistoris p-bazaSi, rac iwvevs n^+-emiteris eleqtronebis Semxvedr inJeqcias. gaSvebis sawyis periodSi P_1 koleqtorul plazmur SreSi muxtebis balansi yovelTvis uaryofiTia da mxolod mas Semdeg xdeba dadebiTi, ramdenadac ganviTardeba inJeqcia tranzistorSi kaTodze. es warmoadgens principul sakiTxs reversiulad CarTvadi dinistoris CarTvis procesis mdgradobisTvis, ramdenadac gaRaribebul P_1 Sres Tan axlavs koleqtoruli gadasvlis wanacvleba Camketi mimarTulebiT da xelsawyoze Zabvis mkveTri zrda. CarTvis Semdegi procesi kontroldeba Cveulebrivi tiristoruli meqanizmiT. amitom didi denebis erTgvari komutacisTvis saWiroa gaJRenTvis sakmarisad maRali done, raTa P_1 mmarTveli plazmuri Sre da p-baza warmoqmnas erTad. aseve, gamdidrebuli plazmuri rezervuari warmoadgens eleqtronebis efeqtur wyaros. aseTi rezervuaris rols diodSi asrulebs kaToduri emiteri. amitom CarTvis am reJims ganixilaven rogorc kvazidiodur reJims [11].

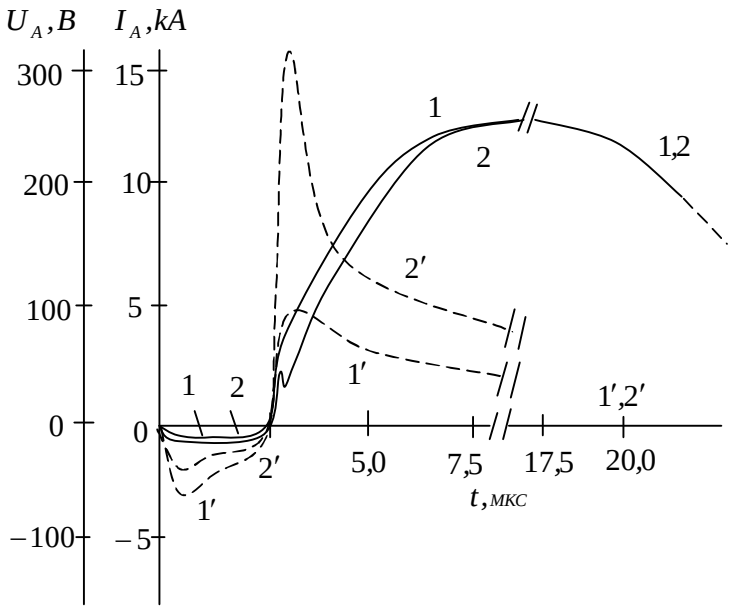
bipolaruli dreifuli talRis yofaqceva Seqcevadia I_t denis mimarTulebis mimarT. roca $t > t_R$ anoduri denis cvlilebisas ukumimarTulebidan ($I_R < 0$) pirdapiri mimarTulebisken ($I_R > 0$) sawyisi reversiuli talRis (P_r) profilis yvela wertilis CaTvliT iwyebs moZraobas sapirispiro mimarTulebiT.



nax. 3.13. rCd-is tiristoruli elementebis CarTvis procesi. a _ Zalovani konturis eqvivalenturi sqema $t > t_R$; b _ plazmuri Sreebis procesebis dinamika sxvadasxva etapebze.

reversiulad CarTvadi dinistoris gaJRenTvis xangrZlivoba Cveulebriv ar aRemateba $2 \cdot 10^{-6}$wm, ganmamxoloebeli droselis

procesis xangrZlivobisas miiReba Zalian didi gabaritebi, roca I_R gaJRenTvis denis simkvrive aris 100a/sm^2 , $Q_R = 2\cdot10^{-4}$kul. Tu CavTvliT diodis emiters idealurad, maSin $\left(\frac{dI_F}{dt}\right)_{kp} = 5{,}7\cdot10^2$ a/smwm. Tu xelsawyos muSa farTobia 20sm^2, maSin $\left(\frac{dI_F}{dt}\right)_{kp} \approx 1\cdot10^5$ a/mkwm.



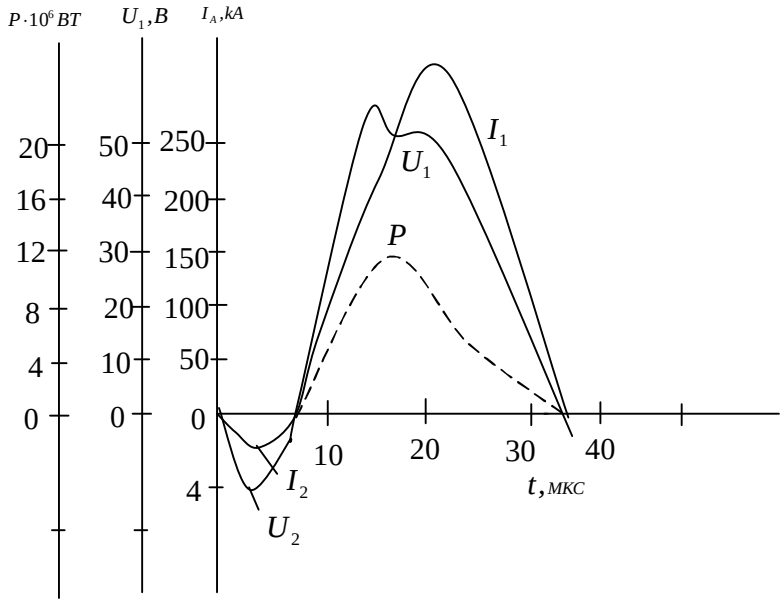
nax. 3.14. denis (1, 2) da Zabvis $(1', 2')$ oscilogramebi rCd-s komutaciisas.

$1, 1' - Q_R = 120$ mkkul/sm^2; $2, 2' - Q_R = 60$ mkkul/sm^2

nax. 3.12-ze naCvenebia rC dinistoris muSa farTobis 4sm^2-is gadarTvis oscilogramebi. tranzistoruli elementis n^+-tipis emiteri warmodgenilia gadafarvis badis saxiT, romlis zolis sigane 50mkm-ia, manZili zolebs Soris (tranzistoruli elementebis sigane) Seadgens 200mkm-s. siliciumis kuTri winaRoba $\rho_n = 100$ omism, n-bazis sisqe ki tolia 200mkm. saerTo p-bazis sisqe, romelic miiRebulia borisa da aluminis erToblivi difuziiT, maTi koncentraciebi ki Sesabamisad aris $2\cdot10^{18}$ da $1\cdot10^{16}$ sm^{-3}, Seadgens 60mkwm-s. sawyis ubanze $\frac{dI_F}{dt} = 2\cdot10^3$ a/mkwm$\cdot$sm^2, xolo imrudisTvis $Q_R = 120$ mk.kul/sm^2 da

$\left(\frac{dI_F}{dt}\right)_{kp} = 3{,}5\cdot10^3$ a/mkwm·sm^2, es monacemebi sakmaod didia, vidre eqsperimentSi da rCd-s CarTva kvazidiodur reJimSi. Q_R-is Semcirebisas 60 mkkul/sm^2 –mde (mrudi 2) $\left(\frac{dI_F}{dt}\right) = 1{,}8\cdot10^3$ a/mkwm·sm^2, kvazidioduri reJimi irRveva.

rodesac Seyovnebis xangrZlivoba izrdeba 1.5-2mkwm-mde, praqtikulad yvela xelsawyo mwyobridan gamodis 2-3ka denis komutaciisas, amis gamo iwyeba Zlieri lokalizaciis procesi. nax. 3.13-ze naCvenebia xelsawyoSi mimdinare komutaciis procesis oscilograma naxevargamtaruli struqturis konstruqciaze dayrdnobiT, romlis farTobi aris 20 sm^2, xolo muSa Zabva ki 1.5kv. xelsawyo muSaobs kvazidiodur reJimSi ($Q_R \approx 8\cdot10^{-3}$ kul) da axdens Zalian didi denis (~270ka) komutacias frontis zrdis siCqariT $\frac{dI}{dt} > 75$ ka/mkwm.



nax. 3.15. denis komutaciis oscilograma mZlavri rCd-Ti.

I_1, I_2 - Sesabamisad aris deni Zalovan wredSi da gaJRenTvis wredSi; U_1, U_2 - Sesabamisad aris narCeni Zabva da gaJRenTvis Zabva; P - aris xelsawyoSi danakargebis simZlavre.

narCen Zabvas gaaCnia umniSvnelo rxeva wina frontze da kvazistacionaruli mdgomareoba myardeba daaxloebiT 4mkwm, rac metyvelebs dinistoris erTganzomilebian CarTvis xasiaTze, rodesac Cveulebriv tiristorebSi es procesi daikavebda 100-150mkwm. amitom SeiZleba wina frontis komutaciuri danakargebis ugulebelyofa kvazistacionarul reJimTan SedarebiT. am danakargebis simcire da maTi Tanabari ganawileba mTeli farTobis gaswvriv ganapirobebs reversiulad CarTvadi dinistoris unikalur sakomutacio maxasiaTebels. aRsaniSnavia, kidev erTi mniSvnelovani Tavisebureba _ dinistoris muSaobisas kvazidiodur reJimSi gaJRenTvis denis Sewyvetisas CarTvis procesis xangrZlivoba nulis tolia. es uzrunvelyofs mimdevrobiT da paraleleurad SeerTebuli nebismieri raodenobis xelsawyoebis mkacr sinqronul CarTvas erTi generatoris muSaobis dros, anu saSualebas iZleva Seiqmnas praqtikulad SeuzRudavi simZlavris impulsebis generatorebi.

reversiulad CarTvadi dinistoris danarCeni maxasiaTeblebiTanafardoba muSa Zabvas, gamorTvis drosa da narCen Zabvas Soris stacionarul CarTul mdgomareobaSi, $\frac{dU}{dt}$ _ medegoba, parametrebis temperaturuli damokidebulebebi, daaxloebiT analogiuria Cveulebrivi mZlavri tiristorebis maxasiaTeblebisa [24,33].

danakargebis mcire absoluturi da kuTri sidideebi rC dinistoris CarTvisas saSualebas iZleva mniSvnelovnad aamaRlos sixSiruli zRvari uwyveti rxevebis generaciis reJimSi muSaobisas. tiristoruli tipis xelsawyoebis zRvruli muSa simZlavre SezRudulia yvelaze neli gardamavali procesis xangrZlivobiT da kargvebis sididiT naxevargamtarul struqturaSi. t_B gamorTvis dro principSi SeiZleba iyos mcire (mikrowamis rigis), amitom xelaswyoze muSa Zabva SedarebiT mcirea (300_600v), xolo zRvruli sixSire moTavsebulia megahercis diapazonSi. danakargebi naxevargamtarul struqturaSi Sedgeba ori komponentisagan: CarTvisas da gamorTvisas sakomutacio danakargebis da

kvazistatikuri danakargebisgan, romelic warmoiqmneba denis pirdapiri mimarTulebis gavlisas. Cveulebriv tiristorSi aTeul kiloherc sixSireze Warbobs sakomutacio danakargebi da swored isini zRudaven sixSirul zRvars 10-15khc doneze. reversiulad CarTvad dinistoris CarTvisas sakomutacio danakargebi Zalian mcirea, xolo gamorTvisas danakargebi praqtikulad ar arsebobs ukumimarTulebis denis Sewyvetis gamo, romelic warmoiqmneba swrafmoqmedi diodis mimdevrobiTi CarTvisas.

naxevargamtaruli diodis aRdgenis process misi gadrTvisas pirdapiri wanacvlebidan arapirdapirze, garkveul pirobebSi Tan axlavs masze Zabvis mkveTi zrda. es procesi Sedgeba ori etapisagan. pirvel etapze diodis bazaSi inJeqcirebuli gadamtanebis koncentracia pirdapiri denis gavlisas mniSvnelovnad aRemateba wonasworuls. am etapze (maRali ukugamtarobis faza) Zabva diodze mcirea, xolo deni SezRudulia datvirTvis winaRobiT. meore etapze ki xdeba moculobiTi muxtis areebis warmoqmna gadasvlebTan, da am etapis dasasruls, yvela gare Zabva daiblokeba diodis mier. Zabvis aRdgenis procesi SeiZleba iyos Zalian swrafi, Tu bazaSi arsebobs Zlieri damamuxruWebeli veli, romelic warmoqmnilia minarevebis koncentraciis gradientiT. aseTi diodebi _ diodebi dagrovili muxtiT qmnian nanowamis Zabvis naxtomebis impulsebs. am diodebis muSa Zabva SedarebiT mcirea (aTeuli volti), radgan minarevebis koncentraciis didi gradientis misaRebad aucilebelia legirebis maRali done. maRalvoltian diodebSi erTgvarovani legirebuli baziT Zabvis aRdgenis procesi Cveulebriv pirobebSi principulad ver uzrunvelyofs maRal swrafmoqmedebas, radganac $p-n$ gadasvlis moculobiTi gafarToeba aRdgenisas muxruWdeba eleqtronul-xvreluri plazmiT, romelic avsebs bazis kvazineitralur nawils. aseTi procesebis xangrZlivobis dro moTavsebulia mikro da submikrowamis diapazonSi.

maRalvoltian diodebSi aRdgenis procesi mimdinareobs Zalian swrafad. aseTi diodebs uwodes dreifuli diodi swrafi

aRdgeniT (ddsa). aRmoCnda, rom nanowamis diapazonis maRalvoltiani diodis aRdgenisaTvis aucilebelia mablokirebeli $p-n$ gadasvlis plazmuri Sre iyos sakmaod Txeli. aseTi Sris Sesaqmnelad aucilebelia gaJRenTvis denis impulsi iyos Zalian mcire, amitom TandaTanobiT xdeba moculobiTi muxtis gafarToeba, romelic warmoiqmneba denis gaJonvis adgilas, da masze vardeba muSa ZabvasTan SedarebiT naklebi Zabva. aseTi fenis warmosaqmnelad aucilebelia, rom gaJRenTvis I_F pirdapiri denis impulsi iyos Zalian viwro.

dreifuli diodis swrafi aRdgenis gajerebis procesi pirdapiri mimarTulebis denis impulsiT arafriT gansxvavdeba reversiulad CarTvad dinistorSi mmarTveli plazmuri Sris Seqmnis procesisagan. uku mimarTulebis ZabviT swrafi aRdgeniTi procesi diodze iwyeba mxolod mas Semdeg, rodesac bazidan xdeba yvela araZiriTadi matareblebis sruli gaqroba. am momentamde xelsawyoze mimdinareobs Zabvis TandaTanobiTi zrda.

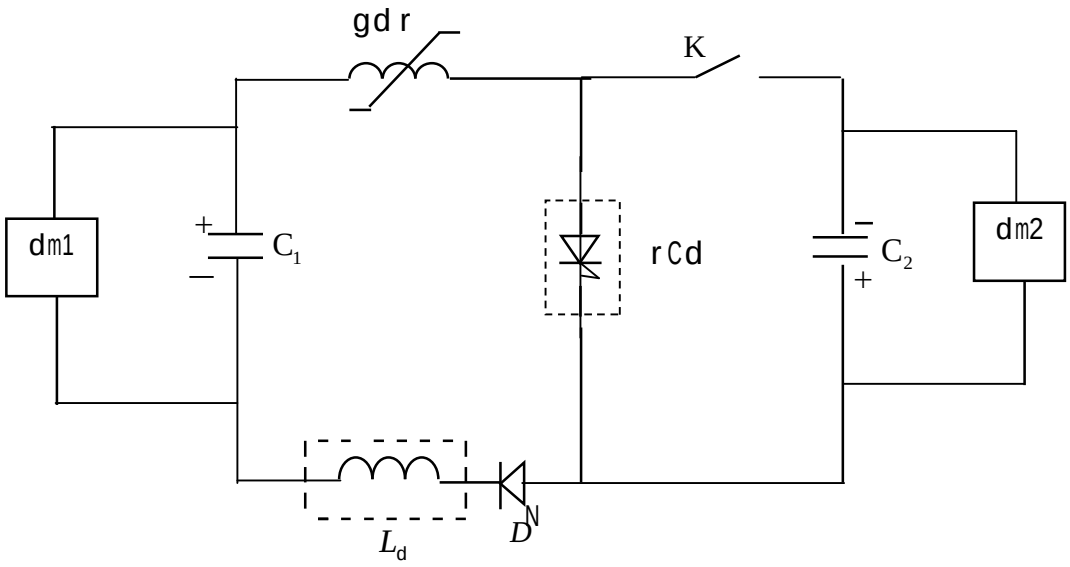
denis cvlilebisas dreifuli diodis swrafi aRdgenisa da gaJRenTvis fizikuri procesebis analizi mimdinareobs etapobrivad. dreifuli diodi swrafi aRdgeniT gamoiyeneba, rogorc gamosavali impulsis amaCqarebeli, romelic Cveulebriv izrdeba sakmaod nela, wrfivi an sinusoiduri kanoniT. procesebi dreiful diodSi swrafi aRdgeniT xasiaTdeba swrafi aRdgenis momentamde integraluri parametrebiT: gaJRenTvisas dagrovili sruli muxtiT, am muxtis nawiliT, romelic Tavmoyrilia difuziur plazmur SreSi da am fenis sisqe aris $L \cong \sqrt{Dt_F}$. es parametrebi ar aris damokidebuli denis impulsis konkretul formaze. swrafad aRdgenis procesi ganisazRvreba am procesis dasawyisSi denis myisieri mniSvnelobiT.

3.7. komutatoris marTva

ganvixiloT rC dinistorebiani komutatoris marTvis sakiTxebi stu-Si damuSavebuli K16-08 tipis magnitur-impulsuri danadgaris magaliTze, romelic garkveuli modernizaciis Semdeg

SeiZleba gamoyenebuli iqnes maRalsixSiruli piezoeleqtruli aCqarebis gamzomi gardamsaxis diagnostirebisTvis. kerZod, masSi ignitronuli ganmmuxtavi UPT-2 marTvis sistemiT unda Canacvldes rC dinistorebis wyobiliT Sesabamisi marTvis sistemiT. modernizebuli K16-08 danadgari Seicavs impulsuri mcire induqciurobis mqone kondensatorebis batareas (ori ИК-25-12у4 tipis kondensatori saerTo tevadobiT 24 mkf), dammuxtav mowyobilobas, muSa organos _ induqtors da marTvis sistemas. danadgaris muSa Zabva aris 10kv, impulsuri denis pikuri mniSvneloba aris 100ka impulsis xangrZlivobiT 10mkwm. 2kv-iani rC dinistorebis gamoyenebisas, maTi raodenoba komutatoris wyobilSi iqneba 5. komutatorSi gaTvaliswinebulia momkveTi diodi ДЧ-2000-22б, romlis muSa farTobi aris 20sm^2. impulsur reJimSi aseTma komutatorma SeiZleba gadarTos L100ka deni 10kv Zabvisas, roca impulsis xangrZlivoba aris 10mkwm. [19].

nax. 3.16-ze naCvenebia modernizebuli magnitur-impulsuri danadgaris sqema rC dinistorebiani komutatoriT.

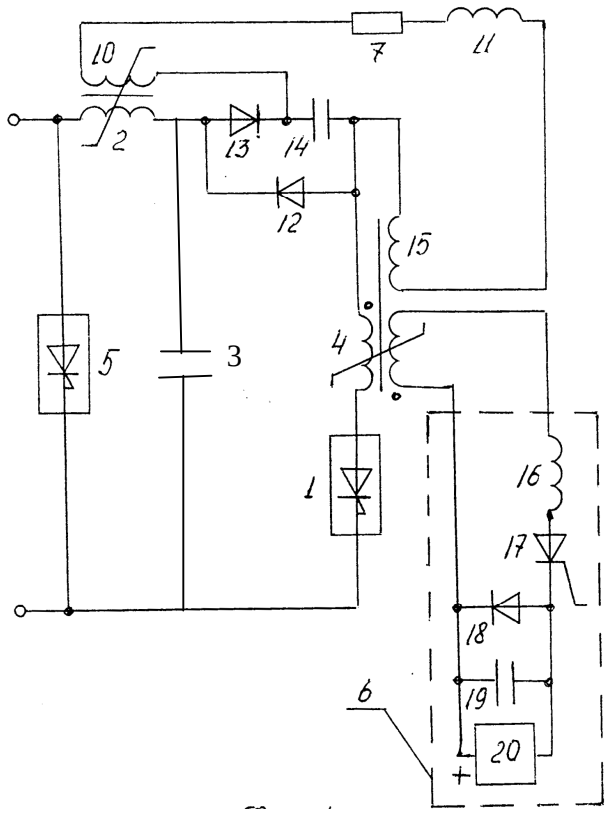


nax. 3.16

aq C_1 kondensatorebis batareaa, L_d induqtori _ muSa organo. modernizaciis Sedegad danadgars daemata D mokveTis diodi, reversiulad CarTvadi dinistorebis wyobili, gaJRenTvadi

droseli (gdr) da damatebiTi kondensatorebis batarea C_2. dm1 da dm2 _ kondensatorebis dasamuxti mowyobilobebi. rodesac K gasaRebi gaxsnilia damuxtuli damatebiTi kondensatorebis batarea C gaTiSulia. ZiriTadi kondensatorebis batarea agreTve gaTiSulia L_d induqtorisgan komutatoriT rCd da droseliT gdr. K gasaRebis CaketviT damatebiTi kondensatorebis batarea aRmoCndeba mierTebuli komutatoris momWerebTan, ganimuxteba maszed sawinaaRmdego mimarTulebiT da gaCndeba dinistorebis gamSvi deni, romelic maTSi Camoayalibebs mmarTvel plazmur fenas. am dros droseli aris gauJRenTav mdgomareobaSi da aCerebs denis zrdas C_1 batareidan C_2 batareisken. droselze modebulia C_1-is Zabva mTlianad. es droseli isea gaTvlili, rom misi gaJRenTva iwyeba dinistoris gamSvi denis formirebis Semdeg, e.i. K gasaRebis amoqmedebidan 1-2mkwm Semdeg. droselis gaJRenTvis Semdeg rC dinistorebze, romlebSic ukve Camoyalibebulia mmarTveli plazmuri fena, kvlav miewodeba C_1 batareis sruli Zabva. komutatori gadairTveba da masSi induqtoriT gaivlis kondensatorebis ganmuxtvis mZlavri impulsuri deni. [20,21].

unda aRiniSnos, rom K gasaRebi gaTvlili unda iyos C_1 da C_2 kondensatorebis jamur Zabvaze, Tumca misi komutirebuli deni SeiZleba ramdenime rigiT naklebi iyos komutatoris denTan SedarebiT. K gasaRebi gamodis komutatorze ufro maRali Zabvis mowyobiloba, rac garkveul sirTuleebs qmnis komutatoris damuSavebisa da eqspluataciis procesSi. danadgaris muSaobis saimedobaze mniSvnelovan gavlenas axdens agreTve gajerebadi droselis magnituri mdgomareobis stabilizacia. amitom ganvixiloT sqema, romelic Seicavs 1 rCd-s bloks, 2 arawrfiv elements



nax. 3.17

gaJRenTvadi gulariT _ droselis saxiT, 3 meore kondensators, 4 amamaRlebel transformators gaJRenTvadi gulariT, 5 rC dinistoris meore bloks, 6 gaSvebis bloks, 7 rezistors, 8 Sesasvlel momWers, 9 gamosasvlel momWers, 10 ganmamagnitebeli droselis gragnils, 11 induqciur elements, 12 meore diods, 13 pirvel diods, 14 pirvel kondensators, 15 amamaRlebeli transformatoris ganmagnitebis gragnils, gamSvebi blokis: 16 induqciur elements, 17 tiristors, 18 diods, 19 kondensators, 20 damuxtvel mowyobilobas.

ganvixiloT mocemuli sqemis muSaobis principi: gamSveb blok 6-Si dasamuxti mowyobiloba 20-dan mcire Zabvaze damuxtuli kondensatori 19 ganimuxteba 17 tiristoris CarTvisas. ganmuxtvis deni induqciuri elementis 16 gavliT miaRwevs amamaRlebeli transformatoris 4 pirvelad gragnils, amitom 4 transformatoris meorad gragnilze warmoiSoba Zabvis mokle impulsi, romlis amplituda sididiT aRemateba Zabvas meore

kondensatorze 3, romelic sididiT tolia Zabvisa Sesasvlelze. xdeba kondesatoris 3 damatebiTi damuxtva meore diodiT 12, transformatoris meoradi gragniliT 4 da rCd 1 pirveli blokiT. damuxtul kondensator 3-ze arsebuli deni warmoadgens rCd 1-is marTvis dens. transformatori 4-is gularas gaJRenTvisas rCd 1 akomutirebs swrafad mzard denis impulss kondensatorze 3, romlis gadamuxtva xdeba transformatori 4-is meoradi gragniliT, pirveli diodiT 13 da pirveli kondensatori 14-iT. garkveuli drois Semdeg kondensatorze 3 xdeba Zabvis polarobis Secvla, iJRinTeba droseli 2-is gulara da misi induqciuroba mkveTrad mcirdeba da kondensatori 3 ganmeorebiT gadaimuxteba da gaiReba rCd 5. deni kondensatorze, romelic gaivlis rCd 5-Si da gaaRebs mas, warmoadgens mmarTvis dens. bloki rCd 5 akomutirebs mZlavr gamosasvleli denis impulss, romelic aformirebs gare wreds. komutaciis procesis Semdeg rezistori 7-iT, induqciuri elementi 11-iT da ganmagnitebis gragnilebiT 10 da 15-iT xdeba kondensatori 14-is ganmuxtva, aseve droseli 2-is gulara da transformatori 4 iwyeben ganmagnitebas magnituri mdgomareobis stabilizaciisTvis da Semdgomi komutaciis procesisaTvis.

mocemuli sqemis mixedviT meore kondensatori 3, meore diodi 12, rCd meore bloki 5 da amamaRlebeli transformatori gaJRenTvadi gulariT 4 arsebiTad amcirebs denis amplitudas maformirebel gamSveb blokSi, rogorc rCd gamSvebi bloki 1 Sedgeba mciresimZlavriani dinistorebisagan, romelebsac gaaCniaT mcire muSa farTobi da mcire marTvis deni. garda amisa, rezistori, induqciuri elementi, droselis da amamaRlebeli transformatoris ganmagnitebis gragnilebi astabilureben droselis magnitur da amamaRlebeli transformatoris gularebis mdgomareobas komutaciis procesis dasrulebis Semdeg uku ganmagnitebis xarjze. gamSvebi blokis elementebis gavliT denis amplitudis Semcireba da droselis magnituri mdgomareobis da amamaRlebeli transformatoris stabilizacia iZleva mowyobilobis saimedoobas (xanmedegobas).

mocemul sqemaze SemoTavazebuli mowyobilobis muSa Zabva aris 10kv, kondensatorebis 3 da 14 tevadobebi Sesabamisad tolia 0.2mkf. da 20mkf. 1 da 5 blokebSi gamoyenebuli rCd muSa Zabva aris 2kv. mciresimZlavris bloki rCd 1 Sedgeba xuTi mimdevrobiT SeerTebuli mowyobilobisgan, romelTa muSa farTobia 4sm^2, xolo mZlavri bloki rCd 5 Sedgeba xuTi mimdevrobiT SeerTebuli mowyobilobisgan muSa farTobiT 20sm^2. droselis 2 da transformatoris 4 gularebi damzadebulia wriul-lenturi magnituri wredisgan zomiT 90*40*20mm. transformatoris 4 transformaciis koeficientia 15 (pirvelad gragnilze erTi xvia, xolo meorad gragnilze 15). rezistoris winaRoba 7-30omi, induqciuri elementebis 11 da 16 induqciurobebi Sesabamisad aris 100mkhn da 0.5mkhn. kondensatoris 19 tevadoba aris 5mkf. diodebis 12, 13 da 18 tipebi _ ДЛ 132-50-12, rezistoris tipi 17-ТБ 151-50-12. dammuxtveli mowyobiloba 20 Seicavs amamaRlebel qselur transformators, diodur gammarTvels, denis SemzRudvel rezistors da gamosasvlel Zabvas 1kv. [49,50].

3. დასკვნა

Catarebuli gamokvlevebis safuZvelze miRebulia Semdegi Sedegebi:

1. Zlieri impulsuri magnituri veli warmoadgens teqnikuri diagnostikis Zalzed efeqtur saSualebas.
2. magnitur-impulsuri danadgaris, rogorc impulsuri energetikuli mowyobilobis umniSvnelovanes kvanZs warmoadgens komutatori, romelsac waeyeneba sakmaod mkacri da winaaRmdegobrivi moTxovnebi. erTis mxriv, is unda iyos saimedo, xanmedegi da ekonomiurad efeqturi, anu arc ise Zviri da meores mxriv, saWiroa rom man uzrunvelyos didi impulsuri simZlavreebis komutireba didi denebisa da maRali Zabvebis dros.
3. airganmuxtvis xelsawyoebs aqvT principuli naklovanebebi, romlebic ganpirobebulia airSi ganmuxtvis procesis mimdinareobis TaviseburebebiT da zRudaven xelsawyos gamoyenebas zemaRali impuluri simZlavreebis komutirebisas. es upirveles yovlisa, aris amuSavebis arastabiluroba, rac aZnelebs rTuli sistemebis sinqronizacias da dabali xanmedegoba, rac ganpirobebulia ganmuxtvis procesis rkaluri stadiiT gamowveuli eleqtrodebis eriziiT, romelic zRudavs simZlavris Semdgom zrdas.
4. naxevargamtaruli komutatorebi warmatebiT cvlian airganmmuxtav komutatorebs, vinaidan maT aWarbeben xanmedegobiT da muSaobis stabilurobiT. is, rom SesaZlebelia maTi mimdevrobiT da paralelurad SeerTeba, iZleva maTi gamoyenebis saSualebas denebisa da Zabvebis farTo diapazonSi, raTa warmatebiT gadavwyvitoT impulsuri energetikis aqtualuri problemebi.
5. rigma Catarebulma gamokvlevebma (iseTi rogoricaa optimaluri masalebis SerCeva rCd-s kargi kontaqtebis uzrunvelsayofad), saSualeba mogvca uzrunvelgvyo dabali da stabiluri gardamavali eleqtruli da siTburi winaRobebi rCd-s Soris,

rac iZleva xangrZliv garantias da komutatoris muSaobis saimedoobas.

6. axali Taobis reversiulad CarTvadi dinistorebis saSualebiT miiRweva kuTri komutirebadi simZlavris rekorduli maCvenebeli komutatoris erTeulovan farTobze. komutatorebi muSaoben rogorc monoimpulsur, aseve sixSirul reJimSi da gamoiyenebian farTo diapazonis impulsur energetikaSi.
7. rCd-is gamoyeneba msgavsad impulsuri tiristorebiT awyobili komutatorisa saSualebas iZleva induqtorSi gavataroT praqtikulad unipolaruli impulsuri deni, rac gansakuTrebiT mniSvnelovania piezoeleqtruli aCqarebis gamzomi gardamsaxebis diagnostirebis dros, rodesac gazomvebis sizuste didad aris damokidebuli sakvlev obieqtze Semavali Zalovani zemoqmedebis xangrZlivobaze.
8. danadgarSi rCd-s komutatorad gamoyeneba komutirebuli simZlavris zrdasTan erTad saSualebas iZleva gaumjobesdes sadiagnostiko danadgaris metrologiuri maxasiaTeblebi. gamosacdeli obieqtis metrologiuri maxasiaTeblebi _ struqtura, sakuTari rxevebis sixSire, demfirebis koeficienti, mgrZnobiaroba, arawrfivoba, ganisazRvreba mowyobilobis reaqciisa da impulsuri zemoqmedebis speqtralur simkvriveTa fardobiT. es fardoba martivdeba, rodesac impulsuri zemoqmedeba Zalze xanmoklea da uaxlovdeba delta funqcias, rac niSnavs, rom gamosacdeli obieqtis gadacemis funqciisa da reaqciis speqtraluri simkvriveebi praqtikulad Tanxvdenili funqciebia.
9. reversiulad CarTvadi dinistori impulsur energetikaSi warmoadgens maRalefeqtur komutators, romelic xasiaTdeba didi saimedoobiT da xanmedegobiT, rac saSualebas iZleva praqtikulad unipolaruli Zlieri impulsuri denebis generirebis, rodesac xelsawyos muSa farTi maqsimaluradaa gamoyenebuli.

10. reversiulad CarTvadi dinistorebis gamoyeneba magnitur-impulsur diagnostikur an teqnologiur danadgarebSi saSualebas iZleva didi sididis denebis komutaciiT moxdes Zlieri da xanmokle impulsuri magnituri velebis generireba da Sesabamisad maRalefeqturi teqnologiuri procesebis ganxorcieleba.
11. reversiulad CarTvadi dinistorebis komutatorad gamoyeneba magnitur-impulsur diagnostikur danadgarebSi saSualebas iZleva Seiqmnas Zlieri unipolaruli impulsuri denis generatori, romelic warmoadgens magnitur-impulsuri sadiagnostiko danadgaris ZiriTad nawils.
12. kabelis bunikis mosawnexi magnitur-impulsuri danadgaris modernizacia, masSi ignitronuli ganmmuxtavis reversiulad CarTvadi dinistoruli komutatoriT Canacvleba iZleva piezoeleqtruli aCqarebis gamzomi gardamsaxis diagnostirebis efeqtur saSualebas.

გამოყენებული ლიტერატურა

1. Труды международной раучно-технический конференции. Магнитно-импульсная обработке материалов, пути совершенствования и развития (МИОМ-2007), Самара 2007, стр. 274.

2. Немсадзе Ш.А., Долаберидзе Г.Э. Импулсный метод определения собственных частот ударных измерительных преобразователей ускорения. Метрология, №10, 1981, стр. 32-35.

3. Немсадзе Ш.А.,. Торонджадзе А.Г. Магнитно-импульсная установка. А.С. №877855.

4. Тучкевич В.М., Грехов И.В. Новые принципы коммутаций больших мошностей полупроводниковыми приборами. Л: , Наука, 1988, стр.115.

5. Grekhov I.V., Korotkov S.V., Stepaniants A.L., Khristyak D.V., Voronkov V.B., Aristov Y.V. High-Power Semiconductor-Based Nano and Subnanosecond Pulse Generator With a Low Delay Time. IEEE TRANSACTIONS ON PLASMA SCIENCE, VOL.33, NO.4, AUGUST 2005. p.1240-1244.

6. Грехов И.В., Коротков С.В., Яковчук Н.С. Исследование реверсивно включаемых динисторов в сильноточных импульсных режимах. Электротехника, №3, 1986, стр. 44-46.

7. Дашук П.Н., Зайенц С.Л., Комелъков В.С., Кучинский Г.С., Николаевская Н.Н., Шкуропат П.И., Шнеерсон Г.А. ТЕХНИКА БОЛЪШИХ ИМПУЛЬСНЫХ ТОКОВ И МАГНИТНЫХ ПОЛЕЙ . Атомиздат Москва 1970. стр. 107-267.

8. Власов В.Ф. Элктронные и ионные приборы, 3 изд., М., 1960; Хлебников Н. Н., Элктронные приборы, М., 1966.

9. Готовцев А. А. Справочник металлиста Т. 1. www. nglib. ru.

10. Безуглов В.Г., Беляев С.А,. Галахов И.В, Гаранин С.Г., Григорович С.В., Золотовский В.И., Кинзибаев М.И., Копелович Е.А., Логутенко С.Л., Мартыненко В.А., Муругов В.М., Осин В.А., Пегоев И.Н., Флат Ф.А., Фролов О.В., Хапугин А.А., Чибиркин В.В., Чибиркин Г.Д., Чумаков Г.Д. Новое Поколение Мощных Полупроводниковых Коммутаторов Для Применений Импульсной Энергетики.

11. Тучкевич В.М., Грехов И.В. Новые Принципы Коммутации Больших Мощностей Полупроводниковыми Приборами. Ленинград, «Наука», Ленинградское отделение, 1988. стр. 3-114.

12. Кацнельсон Б.В., Калугин А.М., Ларионов А.С., Электровакуумные электронные и газоразрядные приборы, М., Радио и связь, 1985. http:// ru. wikipedia. org.

13. Справочная книга радиолюбителя-конструктора. Книга 2. Под ред. Чистякова Н.И. М., Радио и связь, 1993. стр.157. http:// ru. wikipedia. org.

14. Генис А.А., Горнштейн И.Л., Пугач А.Б. Ппиборы тлеющего разряда. Киев, Техника, 1970. http:// ru. wikipedia. org.

15. Лабунцов В.А. Кремниевые управляемые вентили-тиристоры, 1964. стр. 360. www. nglib. ru.

16. museliani T., qobalia m. eleqtromowyobilobaTa teqnikuri diagnostika. sagamomcemlo saxli `teqnikuri universiteti". Tbilisi.- 2009 w. - 333 gv.

17. nemsaZe S. a., giuaSvili m. a. piezoeleqtruli sazomi gardamsaxebis magnitur-impulsuri danadgariT diagnostikis sakiTxebi. saerTaSoriso samecniero konferenciis moxsenebebis krebuli. quTaisi 2010 weli.

18. nemsaZe S., naWyebia S., merabiSvili p., geleniZe m., toronjaZe a., geleniZe g., toronjaZe d., giuaSvili m. plazmuri Wavlis aCqarebis meTodi. saqarTvelos patenti GE P 2008 4350 B. AP 2006 009213.

19. nemsaZe S., toronjaZe a., toronjaZe g., giuaSvili m. magnitur-impulsuri danadgari. saqarTvelos patenti GE P 2012 5374 B. AP 2009 11420.

20. nemsaZe S. a., giuaSvili m. a. magnitur-impulsuri, teqnologiuri da gamosacdeli sistemebi reversiulad-CarTvadi dinistorebiT. saqarTvelos teqnikuri universitetis Sromebi. #1(475). Tbilisi, 2010 weli.

21. Nemsadze Sh., Giuashvili M. ON DIAGNOSTICS OF PIEZOCERAMIC MEASURING TRANSDUCER. First International Conference for Students and Young Scientists on Materials Processing Science. Programme and Book of Manuscripts. Tbilisi, 10-13 October 2010.

22. Шнеерсон Г.А. Поля и переходные процессы в аппаратуре с верхсильных токов. –Л: Энергоиздат, 1981, стр. 199.

23. Шнеерсон Г.А., Колтунов О.С., Кривошеев С.И., Адамьян Ю.Э., Березкин А.Н., Дёгтев Д.А., Непашев А.П., Парфентьев А.А., Титков В.В. Возможность получения имрульсных мегагаусных магнитных полей в неразрушаемых квазивессиловых магнитах. Магнитно-импульсная обработке материалов. Сб. Материалов межд. научно-технический конференций МИОМ-2007. Самара 2007г.

24. Горбатюк А.В., Грехов И.В., Коротков С.В. и др. / О новой возможности быстрой коммутаций больших мощностей силовыми полупроводниковыми приборами/ /ЖТФ. - 1982. - Т. 52, №7. - С. 1369-1374.

25. Горбатюк И.В., Грехов И.В., Коротков С.В. и др. / О новой возможности быстрой коммутаций больших мощностей приборами тиристорного типа// Письма в ЖТФ. – 1982. – Т. 8, №11. – С. 685-688.

26. Горбатюк И.В., Грехов И.В., Коротков С.В. и др. / Мощный переключатель микросекундного диапазона-реверсивно включаемый динистор// ЖТФ. – 1983. – Т. 53, № 9. – С. 1882-1826.

27. Горбатюк А.В., Грехов И.В., Коротков С.В. и др.// Двухступенчатый импульсный запуск мощных динисторных переключателей// Электротехника. – 1984. - №11. – С. 42-45.

28. Грехов И.В., Костина Л.С., Коротков С.В. // Мощный реверсивно включаемый динистор субмегагерцового диапазона// Письма в ЖТФ. 1985. Т. 11. №10.

29. Сырников Э.В. К анализу ключевого генератора гармонических колебаний на управляемых вентилях// Техника средств связи. Сер. ТРС. 1979. Вып. 5.

30. Брылевский В.И., Грехов И.В., Кардо-Сысоев А.Ф., Чашников И.Г./ Мощный высоковольтный быстродействующий коммутатор./ – ПТЭ, 1982, №3, с. 96-99.

31. Панютин Е.А., Чашников И.Г. О распределении плотности тока по области первоначального включения тиристоров в режиме с высоким быстродействием. – Радиотехника и электроника, 1978, №4, т. 23, с. 883-886.

32. Брылевский В.И., Кардо-Сысоев А.Ф., Левинштейн М.Е., Чашников И.Г./Механизм локализации тока в процессе включения субмикросекундных модуляторных тиристоров. - Письма в ЖТФ, 1982, Т. 8, №21, с. 1288-1292.

33. Грехов И.В., Чашников И.Г. О влиянии краевых эффектов на распределение тока в мощных полупроводниковых приборах. - Письма в ЖТФ, 1977, т. 3, вып. 24, с. 1343-1345.

34. Ахмедова М.М., Кардо-Сысоев А.Ф., Чашников И.Г., Шуман В.Б. /Исследование однородности включения тиристоров во время формирования фронта. – Физика и техника полупроводников, 1975, т. 9, вып. 4, с. 817.

35. Грехов И.В., Кардо-Сысоев А.Ф., Крикленко А.В. Управление мощными полупроводниковыми переключателями с помощью СВЧ-излучения.– ФТП, 1982, № 9, т. 16, с. 1572-1579.

36. Белов А.Ф., Воле В.М., Воронков В.Б., Грехов И.В. /К вопросу о переключении тиристоров эффектом dU/dt. – Радиотехника и электроника, 1971, №9, т. 16, с. 1736-1738.

37. Волле В.М., Воронков В.Б., Грехов И.В. и др./Мощный наносекундный тиристорный переключатель, коммутируемый импульсом света. – ЖТФ, 1981, т. 51, вып. 2, с. 373-379.

38. Fletcher N.H. Some aspects of design of power transistors. – Proc. IEEE, 1955, vol. 43, №5, p. 551.

39. Brewster I.B., Sherbondy G.F. Complete characteriretion studes verify RBDT-RSR reliability. – ED puls Power modulator Sump. 13th , Buffalo (№4) 1978 Conf. record, p. 252-258.

40. Сырников Э.В. К анализу ключевого генератора гармонических колебаний на управляемых вентилях // Техника средств связи. Сер. ТРС. 1979. Вып. 5.

41. Ramezani E., Spahn E., Bruderer G. <<A novel high current rate SCR for pulse power applications>>// Proceeding of 11th IEEE International Pulsed Power Conference, (1997) 1016-1021.

42. Ibuka S., Osada T., Jingushi K. et al. <<Pulsed power generator utilizing fast Sithyristors for environmental applications>>, //Proceeding of 12th IEEE International Conference (1999).

43. Okamura K., Shimumara H., Kobayashi N., Watanabe K. <<Development of a semiconductor switch for high power copper varop lasers>>, // Proceeding of 11th IEEE International Pulsed Power Conference, (1997).

44. Chumakov G.D., Galakhov I.V., Gudov S.N. et al. ,,Switching of High-Power Gurrent Pulses up to 250kA and Submillisecond Duration using New Silicon Devices-Reverse Switched Dinistors" Proceeding of 10th IEEE International Pulsed Power Conference, (1995) 1103-1108.

45. Savage M.E. ,,Final Results From the High-Current, High-Action Closing Switch Test Program at Sandia National Laboratories" Proceeding of 12th IEEE International Conference (1999) 1238-1241.

46. Beznasyuk N.N., Galakhov I.V., Garanin S.G. et al. "The four-channel laser facility LUCH-a module of the ISKRA-6 facility"// Proceeding of XXVII European Conference on Laser Interaction with Matter ECLIM-2002 (2002).

47. Geifman E.M., Grekhov I.V., Korotkov S.V. et al. “Design and Experimental Investigaition of Asymmetric Reverse-Switched Dynistors.”// Proceedings off 45 Power Converters& Intelligent Motion (PCIM 02), May 14-16, 2002.

48. Тучкевич В.М., Грехов И.В. ,,Новые принципы коммутации больши мощностей полупроводниковыми приборами”, Л., “Наука”, 1988г.

49. Грехов И.В., Коротков С.В. Основные принципы построения мощных импульсных и высокочастотных генераторов на основе реверсивно включаемых динисторов. Электротехника, 1991, №11, с. 27, рис. 3.

50. Грехов И.В., Коротков С.В. Основные принципы построения мощных импульсных и высокочастотных генераторов на основе реверсивно включаемых динисторов. Электротехника, 1991, №11, с. 28.

51. Grekhov I.V., Korotkov S.V., Stepaniants A.L., Khristyak D.V., Voronkov V.B., Aristov Y.V. High-Power Semiconductor-Based Nano and Subnanosecond Pulse Generator With a Low Delay Time.//IEEE TRANSACTIONS ON PLASMA SCIENCE, 2005. VOL.33, AUGUST NO.4, p.1240-1244.

52. Сидоров В.А., Ошовская Е.В., Ченцов Н.А., Проскуряков С.В. Определение рационального времени диагностирования. //УДК 669.02/ 09. 658.58.

53. Немсадзе Ш.А., Долаберидзе Г.Э. Анализ процессов в системе механический волновод-преобразователь ускорения при ударном движении. «ИЗМЕРИТЕЛЬНАЯ ТЕХНИКА», 1978. №1, стр.60-61.

54. Nemsadze Sh., Dolaberidze G. Pulse method of determination of natural frequencies of impact measuring acceleration transducers. Metrologia. 1981, No 10, p.32-35.

55. Sidorov V.A., Oshovskaya E.V., Chentsov N.A., Proskuryakov S.V. Determination of rational time of diagnostics. UDC 669.02/09.658.58.

56. Nemsadze Sh., Dolaberidze G. Analysis of the processes in the system of mechanical waveguide-acceleration transducer at impact motion. “Izmeritelnaya tekhnika”, 1978. No 1, p.60-61.

57. Немсадзе Ш.А., Торонджадзе А.Г.Установка для магнитно-импульсных испытаний. Научные труды ГПИ, 1981, 8(240), с.34-37.

58. Немсадзе Ш.А., Долаберидзе Г.Э. Установка для градуировки пьезоэлектрических измерительных преобразователей ускорения по деформации основания. Научн. Тр. ГПИ, 1974, N1(165), с.78-80.

59. Немсадзе Ш.А., Долаберидзе Г.Э. Установка для определения собственной частоты закрепленного пьезоэлекетрического измерительного преобразователя ускорения. Научн. Тр. ГПИ, 1974, N1(165), с.81-83.

60. Немсадзе Ш.А., Долаберидзе Г.Э. Определение коэффициента влияния деформации на пьезоэлектрические измерительные преобразователи ускорения. Измерительная техника, 1974, N5, с. 29-30.

61. Немсадзе Ш.А., Долаберидзе Г.Э. Стенд для оределения собственных частот датчика ускорения. Авт.свид. N447574, кл. G01h. От 02.12.19721974. БИ N39.

62. Немсадзе Ш.А., Долаберидзе Г.Э. Методика определения собственных частот ударных измерительных преобразователей ускорения. Сообщения АН Грузии, 1975, т.80, N3, с.689-92.

63. Немсадзе Ш.А. Определение ударного ускорения, возбуждаемого импульсным магнитным полем. Научн.тр. ГПИ, 1977, N5 (196), с. 23-25.

64. Немсадзе Ш.А., Немсадзе С.Г., Торонджадзе А.Г. Стенд для определенитя динамических характеристик преобразователей ускорений. Авт. свид. N694816 кл. G01p 21/00. От 3.05.1978. 1979, БИ N40.

65. Немсадзе Ш.А., Торонджадзе А.Г., Пирцхалаишвили А.Н., Багдинов К.А. Установка для магнитно-импульсных иследований. Научн.тр. ГПИ, 1981, N8 (240), с. 34-37.

66. merabiSvili p.T., nemsaZe S.a., wivwivaZe n.v. teqnologiuri daniSnulebis mZlavri magnitur-impulsuri danadgarebis kvleva da damuSaveba. stu-s Sromebi, 1997, №3(414), gv. 48-53.

67. nemsaZe S.a. magnitur-impulsuri teqnologiiT eleqtro-rkaluri plazmatronis kaTodis damuSavebis Sesaxeb. mecniereba da teqnologiebi, 2002, №10-12, gv.91-93.

68. Немсадзе Ш.А., Торонджадзе А.Г. Магнитно-импульсная установка. Авт.свид. N877855, кл.3И21Д 26/14. От 19.12.1979.

69. Немсадзе Ш.А., Долаберидзе Г.Э., Немсадзе С.Г. Устройство для ударных испытаний. Авт.свид. N769380, кл. G01p 21/00. От 26.12.1977. 1980, БИ N37.

70. Немсадзе Ш.А., Долаберидзе Г.Э., Сабахтаришвили В.Б. Ударный стенд для определения динамических характеристик датчиков ускорений. Авт. свид. N492817, кл. G01p 21/00. От 17.06.1974. 1975, БИ N43.

71. Немсадзе Ш.А.,Долаберидзе Г.Э.,Сабахтаришвили В.Б. Стенд для определения динамических характеристик измерительных преобразователей ускорений. Авт. свид. N493734, кл. G01p 15/00. От 16.09.1974. 1975, БИ N44.

72. Немсадзе Ш.А., Торонджадзе А.Г. Определение оптимальной частоты магнитно-импульсной установки. Электричество, 1981, N8, с.48.

73. Немсадзе Ш.А. Источник больших импульсных токов для динамичес-ких испытаний пьезоэлектрических измерительных преобрзователей. Georgian Engineering News, 2003, No.1, p. 170-73.