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ResearchandDesignofEmbeddedSystemforEmissivity Measurement

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Abstract

As an ion generating device, the ion source is widely used in accelerator, space environment and space physics, integrated circuit manufacturing, wafer production, medical and other fields. Emissivity is an important index to indicate the quality of ion source beam. An emittance measurement system for low-energy and high-current ion beams based on the principle of multi-slit single wire measurement was designed and developed. The system includes a step motor, a beam detector (Faraday cup), a weak signal amplifier, isolators and filters, a C8051F500 microcontroller, and a RS-232 interface circuit. Compared with the existing emittance measurement equipment, the system has the advantages of versatility, portability and high cost performance.

Keywords: *Ion source, Emissivity, Measurement, Multi-slit single wire measurement*

1.Introduction

Asaniongeneratingdevice,ionsourceiswidelyusedinaccelerator,spaceenvironmentandspacephysics,integratedcircuitmanufacturing,waferproduction,medicalandotherfields[1-4].Forexample,inanaccelerator,inordertoincreasethevelocityorkineticenergyofchargedparticles,anionsourceisneededtoproducechargedparticlesatfirst.Chargedparticlescanbeacceleratedonlywhentheyaresenttotheacceleratorbyionbeamextractionequipment. Theeffectofaccelerationdependsonthequalityofthebeamproducedbytheionsource.Thebeamqualitydependsonitsemittance,brightnessandenergydivergence,andthemostcommonlyusedisthebeamemittancevalue.Iftheemittancevalueislarge,theparticleswarmwilldisperse,thebeamwillnottransmitwell,andtheaccelerationeffectwillbecomeworse.Iftheemittancevalueissmall,theparticleswarmwillbeconcentrated,whichwillnotonlyfacilitatethebeamtransmission,butalsoproduceagoodbeamaccelerationeffect,andtheacceleratorperformancewillbebetter.Therefore,themoreprecisetheemittancevalueis,thebettertheperformanceoftheacceleratorwillbe,thesimplerthedesignoftheacceleratorwillbe,andtheeasierthestudyofthebeamwillbe[5].

Therearemainlytwokindsofemittancemeasurementmethods,namely,interceptionmeasurementmethodandnon-interceptionmeasurementmethod.In1983,R.H.Milleretal.proposedthatthetransverseemittanceofabeamcanbemeasuredbyabeampositiondetectorwithoutinterception[6].Later,manyresearchersbegantoadoptthismethod.Forexample,in1998,researchersintheLANLLaboratoryintheUnitedStatesusedthismethodtomeasuretransverseemissivityforthefirsttime[7].Janssonetal.proposedthemethodofemissivitymeasurementbyusingmagneticquadrupoleextractorwhichisanothernon-interceptingmeasurementmethod[8].In2007,theresearchersintheEuropeanCenterforNuclearResearch(CERN)usedalaserlinescannertopreciselymeasurethebeamemittanceofthebeamtransportsystemoftheInternationalLinearCollider(ILC)[9].Wangetal.measuredthebeamemittancebychangingthefocusintensityforseveraltimes[10].Xuetal.usedadigitalcameratocapturetheenvelopeofthebeamandchangethefocusintensitytomeasuretheemittance[11].

Songetal.studiedthemeasurementofbeamemittanceby theCT(ComputedTomography)method[12].Masoumzadehetal.usedCSTStudiocodetostudyanddesigntheFaradaycupsbecausetheyarewidelyusedtocharacterizeionbeamcurrent[13].Kazemietal.simulatedtheextractionoftheprotonbeamfromtheduoplasmatronionsourcewith ComputerSimulationTechnology(CST)softwarethroughitsparticletrackingmodule[14].Lietal.developedanemittancemeasurementsystembasedonEPICSsoftware system,tomeasurebeamemittanceofECRionsourcemoreaccuratelyandreliably[15].Ebrahimibasabietal.describedthedesignandconstructionofaMultiArrayFaraday Cupforbothbeamprofilingandcurrentmeasurementsina Penningionsource,andthendesignedatestingset-uptotestandcalibratethesystem[16].Themainmethodsofemissivitymeasurementadoptedinacceleratorsandtheirrespectivecharacteristicsarelistedin Table1.

Forthemeasurementofemittanceofhigh-currentionbeam,thepepperscreenmethod,three-gradientmethodandthree-sectionmethodareallnolongerapplicablebecause ofsomespecialpropertiesofhigh-currentionbeam.AlthoughtheCTmethodhastheadvantagesofhighmeasurementaccuracyanditisnoneedtopresettheinitialbeamemittance,itstechnologyisnotyetmature.Therefore,theslitwiremethodisstillthemostimportantmeasurementemittancemethodofhighcurrentionbeam.Inthispaper,wedesignedanddevelopedanemittancemeasuringinstrumentforlowenergyandhighcurrentionbeamsbasedonmulti-slitsinglewiremethod.

Table1.MainMethodsofEmissivityMeasurementadoptedinAccelerators

Sr. No	Methods	Characteristics
1	Pepper screen/slit-wire method	Interception, low Energy, relieving Space Charge.
2	Magnetic scanning, narrow slit and fluorescent screen	Interception, low Energy, the emittance increases, when energy divergence exists.
3	Cherenkov radiation "dual imaging"	Interception, no need to assume no hypothesis of beam distribution.
4	Single hole sampling	Interception, high current, high pulse momentum, small section.
5	Double screen method	Interception, beam waist positioning
6	Three section (gradient) method	Interception, inclusion of space charge force, hypothesis of ideal ellipse.
7	Six section (gradient) method	Non-interception, high energy, no hypothesis of beam distribution, measure x, y direction emittance simultaneously.

2.MeasurementPrincipleofMulti-slitSingleWireMethod

Thedirectionoftheseamissetas$y$axisandthescanningdirectionofFaradaycupis$x$axis.Themeasurementprincipleofmulti-slitsinglewiremethodisshowninFig.1.Assumingthatthebeamflowisdividedinto$p$unitbeams(thenumberofslits).TheFaradaycupscansinaplanewithadistanceof$L$behindtheseamplate.$x$istheplanecoordinateoftheslit,x'isthedivergenceangle,and$X$istheplanecoordinateoftheFaradaycup.Therootmeansquare(RMS)ofemittancecanbecalculatedaccordingtoEq.(1).

$$\varepsilon_x^2=\frac{1}{N^2}\left\{\left[\sum_{j=1}^{p} n_j\left(x_{sj}-\bar{x}\right)^2\right]\cdot\left[\sum_{j=1}^{p}\left[n_j\sigma_{x'j}^2+n_j\left(\bar{x_j'}-\bar{x}'\right)\right]\right]-\left[\sum_{j=1}^{p} n_j x_{sj}\bar{x_j'}-N\bar{x}\bar{x}'\right]^2\right\} \qquad (1)$$

where, ε_x^2 istherootmeansquareofemittance, $N=\sum_{j=1}^{p} n_j$.Thenormalizedrootmeansquareofbeamemittancecanbecalculatedas Eq.(2).

$$\varepsilon_{xn}=\beta\gamma\varepsilon_n \qquad (2)$$

where, β istherelativisticvelocityofparticles,and $\gamma=(1-\beta^2)^{-1/2}$.

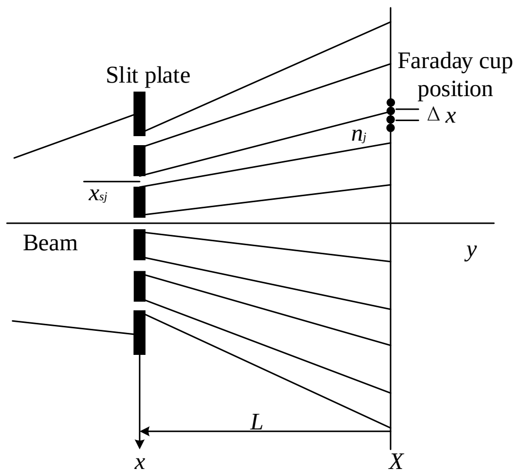

Fig.1.PrincipleDiagramforEmissivityMeasurementofMulti-slitSingleWire

3.SystemArchitecture

Wedesignedanddevelopedanemittancemeasuringinstrumentbasedontheabovemeasurementprinciple.Thesystemstructureisshownin Fig.2,anditincludesastepmotor,abeamdetector(Faradaycup),aweaksignalamplifier,isolatorsandfilters,aC8051F500microcontroller,andaRS-232interfacecircuit.

3.1.BeamDetector

Thebeamdetector(Faradaycup)isresponsibleforconvertingthebeamintensityinformationintoelectricalsignals.TheFaradaycupiscontrolledbythestepmotortomoveradially

3.2.WeakSignalAmplifier

Thissignalproducedbythebeamdetectorisveryweakandcannotmeettherequirementsof A/Dconversion,soaweaksignalamplifiercircuitisneeded.Theconvertedsmallvoltagesignalrangesfrom10to50mV,whilethesamplingvoltagerangeof ADCis0to5V,sothedetectioncircuitamplifiesthesignalmorethan100times.Twostagesofamplificationaresetuphere.Thefirststageamplifierusesahigh-precisioninstrumentamplifier INA111.Inthesecondstageamplifier,theprogram-controlledamplifier MAX4132isselected,byconsideringthatthemeasurementrangeandaccuracyofbeamintensityarecontradictory.Sevenamplificationrangesaresetup,sothattheamplificationcircuitcanautomaticallyselecttheappropriaterangeaccordingtotheintensityofthebeam,andrealizethewiderangeandhighprecisionmeasurementofthebeam.Theweaksignalamplifierwasdesignedas Fig.3.

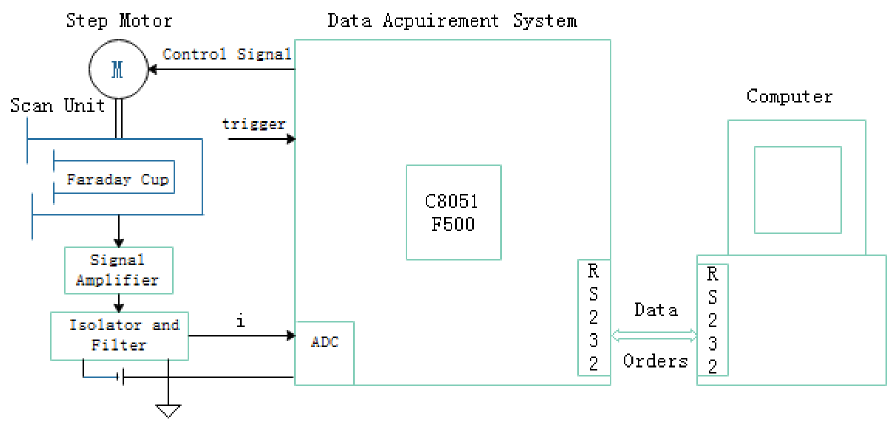

Fig.2.SystemStructureDiagram

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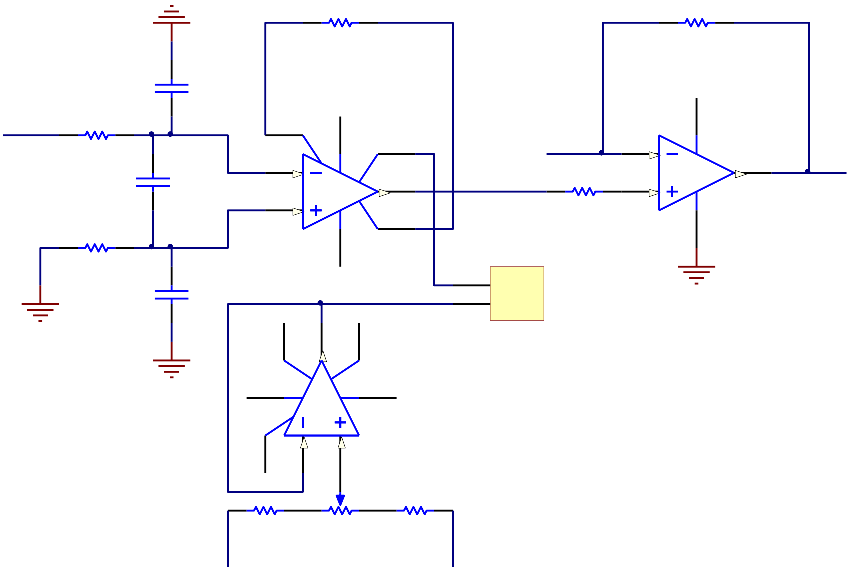

Fig.3.WeakSignalAmplifier

3.3.SignalIsolatorandFilter

Becausetheinterferenceat50Hzcaneasilyenterthemeasurementsystem,a50Hznotchfilterisbuiltbyusinganactivefilter UAF42.Inaddition,inordertocompletelyisolatetheanalogcircuitfromthemicrocontrollercircuitelectricallytoreducetheinterference,aphotocoupleisolationcircuitisaddedattheendoftheconditioningcircuit.Inordertomaximizethebandwidthofthesystem,ahighlinearityoptcouplerHCNR201isselected.TheisolationcircuitisshowninFig.4.

3.4.C8051F500Microcontroller

TheC8051F500microcontrolleristhecoreofthesystem,anditsmainfunctionsareasfollows:

(1)Signalacquisition.TheoutputsignalofoperationalamplifierMAX4132isconvertedtoA/Dafterfilteringandisolatingcircuit.ItisnotdifficulttorealizetheA/Dconversion,becausetheC8051F500microprocessorhasADCconverters.

(2)Controlofthesteppermotor.AtimerintheC8051F500microcontrollerisusedtogenerateacontrolsignal,andanI/Opinofthemicrocontrollerisselectedtooutputthecontrolsignaltocontroltherotationofsteppermotor.

RealizethecommunicationwithPC.ThetransmissionofcontrolcommandanddatabetweenthesystemandPCisrealizedbyRS-232serialport.Inordertorealizetheanti-interferenceisolationoftheinputandoutputofthesystem,adigitalisolatorADUM1402isusedtoisolatethesignallinesTXD0andRXD0ofthecontroller.

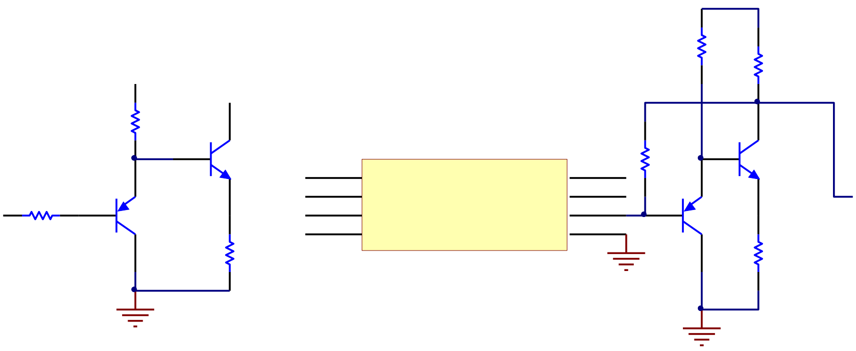

Fig.4.IsolationCircuit

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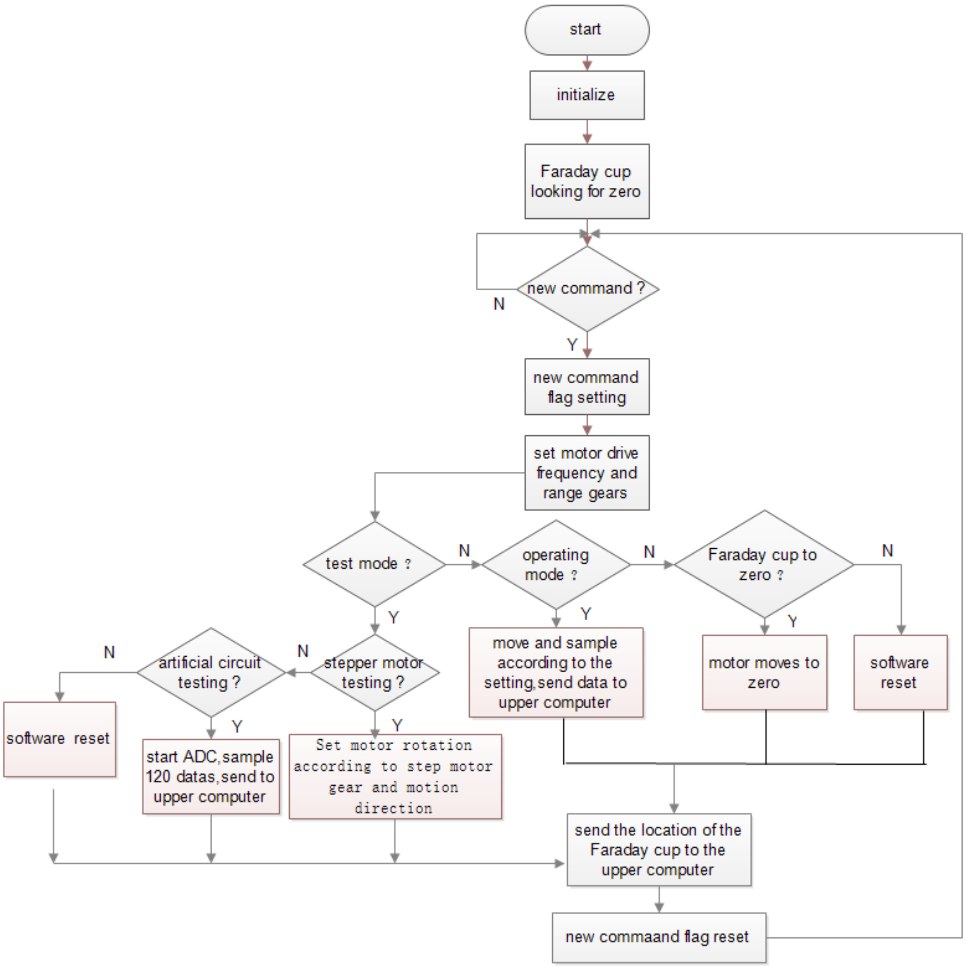


Fig.5.MainProgramFlowoftheSystem

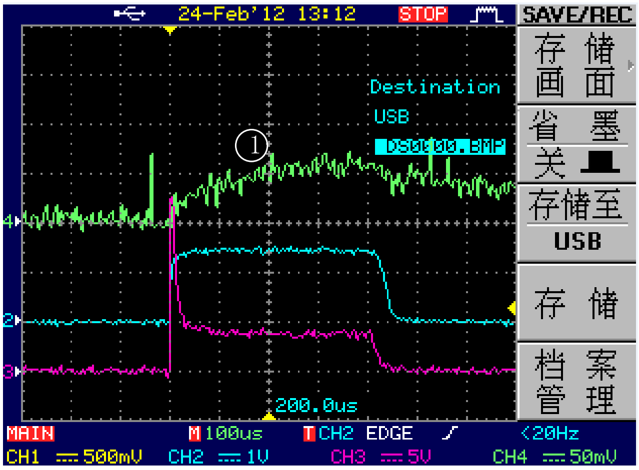
4.SystemSoftwareDesign

Afterinitialization,thesystemreceivesthecommandsignalsentbyPCcircularlybytheserialportinterrupt.Thereceivedcommandsignalisjudgedbytheframeheadandtheframeendatfirst,inordertoensurethecorrectnessofthecommand.Ifthereisanerror,thecommandwillbereceivedagain;ifthereisnoerror,thecommandwillbeparsed.Then,accordingtothecommandtype,thecorrespondingsetupoperationisperformed.Atthesametime,thevoltagedatasampledbyADCissenttoPC.Finally,themeasurementandcontrolfunctionsarecompleted.ThemainprogramflowisshowninFig.5.

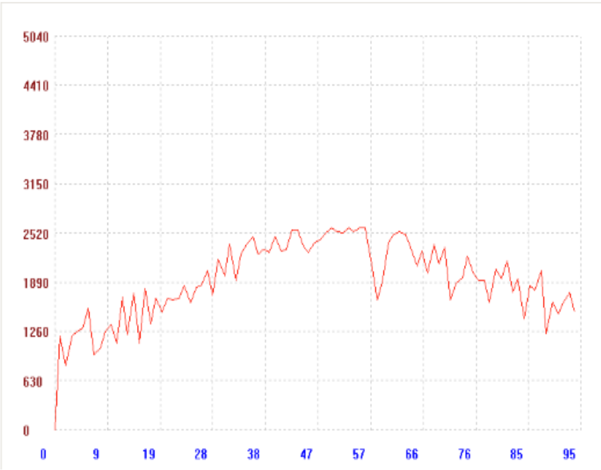
Inadditiontothesystemsoftware,somesoftwareprogramminginneededinPC.ThemainfunctionsofPCareasfollows:(1)realizetheprocessinganddisplayingofsystemstatusinformationandmeasurementresults;(2)sendcontrolcommandstothemeasurementsystem.ThecorrespondingsoftwarewasdevelopedwithMicrosoftVisualC++6.0.ThenormalizedRMSemittancevalueandemittancemeasurementimageareobtainedbyclickingthe"Calculateemittance"buttononthesoftwareinterface.ThedetailedsoftwaredesignprocessinPCisnolongerintroduced.

5.ResultandAnalysis

Theemittanceoftheelectroncyclotronresonance(ECR)ionsourceismeasuredbythedesignedsystem.Firstly,singlepointmeasurementiscarriedout.WhentheFaradaycupmovestothepositionofoneunitbeam,itstopsandrepeatsthemeasurementofthebeamatthepositionofthebeam.Thiskindofmeasurementiscalledsinglepointmeasurement.ThemeasurementresultsareshowninFig.6.InFig.6(a),line ①(green)istheunitbeamcurvemeasuredbyoscilloscope,whileinFig.6(b),themeasurementresultsofthedesignedsystemareshown.



(a)MeasurementResultsofOscilloscope



(b)MeasurementResultsoftheDesignedSystem

Fig.6.SinglePointMeasurementResults

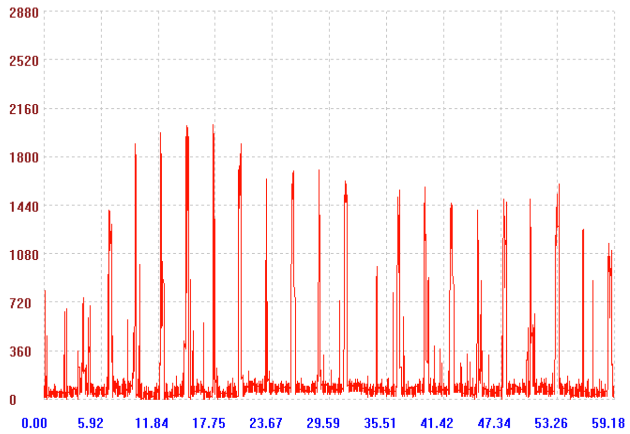


Fig.7.MeasurementResults

Then,allthebeampulsesarerecordedbyadjustingthesamplingfrequencyandscanningspeed.ThemeasurementresultsareshowninFig.7.Itiseasytoseethatthrerearesomesmallburrs,smallpeaksandevenbigpeaksatthebottomofthemeasuringcurve,whicharethebackgroundnoiseofthesystem.Althoughsomenoisesarerelativelylargeandformpeaks,theymostlyexistintheformofpulses,whicharedistinctfromtheslowclimbingofthemainpeak.Mostofthesmallpeaksareuneven,butthebottomofthemeasurementcurveisgenerallyflat,sotheinfluenceofbackgroundnoisecanbeminimizedinthesubsequentemittancecalculationprocess.TheoutputcurrentofFaradaycuprangesfrom0to2000nA,andthemeasurementaccuracyis2%to8%.

6.Conclusions

Basedontheprincipleofmulti-slitsingle-wiremeasurement,anemittancemeasurementsystemisdesignedanddevelopedinthispaper.Aimingattheproblemsofhighvoltagepulsedischarge,complexgroundingandelectromagneticinterferenceinthemeasurementenvironment,aseriesofanti-interferencemeasuressuchasisolation,filtering,shieldingandsingle-pointgroundingareadoptedtoensurethereliabilityofthesystem.Thetestresultsshowthatthesystemhashighmeasurementaccuracyandcanmeettherequirementsofgeneralusers.

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