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PID Controller Parameters Tuning Based on Pole Assignment Optimal Prediction for Power Station Boiler Superheated Steam Temperature

[1]sudhadhara Sarangi, [2]suraj Kumar Lenka
Gandhi Institute of Excellent Technocrats, Bhubaneswar, India
Kruttika Institute of Technical Education, Khordha, Odisha, India

ABSTRACT:
In view of the long-time delay and large inertia ofboilersuperheatedsteamtemperaturecontrol,thispaperproposedaself-tuningcontrolstrategybasedonPoleAssignmentOptimalPrediction.ModelparametersareidentifiedbyLeast squares algorithm with forgetting factor,andthenaccordingtotheestimationmodelofsuperheatedsteam temperature object, the PID parameters are tuned bydesigning the adaptive law with the method of Pole AssignmentOptimal Prediction. Consequently the closed-loop system hasdesired characteristics; also this control strategy can solve theproblemofthelong-timedelayofboilersuperheated steamtemperature.Finallythesimulationresultshaveshownthemethod has good dynamic and static control performances forthiscomplicatedsuperheatedsteamtemperaturecontrolsystem,and meet the actual superheated steam temperature controlrequirements.

IndexTerms—Poleassignment,optimalprediction,forgetting factor, PID parameters tuning, superheated steamtemperature.

INTRODUCTION

PIDcontroliswidelyusedinindustry,forlargernonlinearsystems the parameters of control object often need to betuned at different working points, and the tuning process isnot easy, so the versatility is not strong for different objects.Fuzzycontrol[1],[2]andneuralcontrol[3],[4]fornonlinearsystemcanachievebettercontroleffect,buttheestablishment of fuzzy rules and the application of neuralnetworkmodelarestillbuiltonthebasisofexperience,anditis difficult to obtain the specific description of closed-loopcontrol characteristics.

The pole placement algorithm is a commonly used designmethodwithintuitivelydesignandgooddynamicperformance, which can adapt to the unstable inverse system(non-minimumphasesystem)andopen-loopunstablesystem.The method of pole placement based on input-output transferfunction model is one of the mature control methods amongthemoderncontroltheories.Itcanimplementspecifiedclosedloopcharacteristicsfor linear time-invariant objectandfurther improve thedynamic response and robustness.

Forlargedelayobject,Smith[5]firstlyproposedapredictivecontrollerwhichcouldimprovethecontrolquality.Palmor[6]andWatanabe[7]pointedoutthedefectsinthe practicalapplications,thuslimitingitsapplication.Keyser[8]proposedself-tuningpredictivecontroller,especiallytheapplicationsofself-tuningpredictivePIDcontrollerweregiven,butitsdrawbackisthatthecontrolparameterswerealsochosenbyexperience. Thispaperproposedapoleassignmentoptimalpredictionself-tuningPIDcontrollerwhichcombinedonlineidentificationofthemodelparametersandtheonlinedesignofthecontroller.Theparameteridentificationusedrecursiveleastsquaresalgorithm with forgetting factor, while the controller adoptedpoleassignmentopticalpredictionalgorithm.Themethodnotonlyachievedthedesiredcontrolcharacteristics,andforlarge delay problem of the superheated steam temperature butalso obtained goodcontrol quality.

The superheated steam temperature of high temperaturesuperheater for power station boiler was one of the maincontrolparametersofthethermalcontrolsystem.ThecontrolsystemmainlyadoptedconventioncascadePIDcontrol.Underseriousinterferenceandvariedworkingcondition,itisdifficult to achieve ideal control effect. Hence a lot of newcontrol strategies which combined predictive control methodand the traditional PID control appeared [9]-

[12]. In thispaper, the outer PID parameters tuning adopted the poleassignment optimal prediction algorithm, and combined theinnerPIDcontrollertocontrolthesuperheatedsteamtemperature.
Themainresearchcontentsofthepaperincludethefollowing three aspects. Firstly, aiming at the problem ofmodelparametersestimation,weadopttheleastsquaresalgorithm with forgetting factor. It can effectively identifythe parameters of superheated steam temperature. Secondly,aiming at the superheated steam temperature control systemofPowerStationBoiler,acascadecompoundcontrolstrategy that combines an outer loop PID master controlleradjusted with pole assignmentoptimal prediction algorithmand an inner loop PID auxiliary controller is adopted. Lastly,the simulation of this method is given in this passage. Theresult shows that the proposed method can achieve goodstaticand dynamic performances.

I. THE PIDCONTROLLER

A. TheContinuousPIDController

In a continuous control system, the PID controller canbeen express as

u(t) K_p e(t)
t
e(t)dt T_d 1
de(t)

(1)

T
0
dt I

UseLaplacetransform,soitcanbeenwrittenintransferfunction form
$C(z^{-1})$isweightedpolynomialofthedisturbanceobject.

u(s) 1
A(z^{-1}) 1 az^{-1} ..... a z^{-na}

K 1 Ts

(2)
1 (n)
e(s) p d
Ts

B(z^{-1}) b
bz^{-1} b
z^{-nb} ,(b
0)
I 0 1 (n) 0

C(z^{-1}) 1 cz^{-1} ..... c z^{-nc}

B. TheDiscretePIDController

In a digital system, in order to realize PID control, thecontinuous PID controller should been converted to discretePIDcontroller.IfthesamplingperiodisT$_0$,thediscretePID
controlleruses difference equation toexpress as

where,
1 (n)

[a,a,...a,b,b,...b]^T 1 2 n 1 2 n
a b

1
P T — ∑ 0 k

e(k) e(k 1)
d T

T [y(k 1), y(k 2),... y(k n),
u(k d),u(k d 1)...u(k d n)]
a
u(k) K
(e(k)
I I 0
Te(k i) T
)
0
(3)
b
Thiscanbe writtenin vectorform

Transform(3) byZ-translation
y(k) T C(z 1)e(k)
(7)

u(z) Kp
(e(z) T0
TI
1
1 z 1

e(z)

(4)
Theobservationvector Tandtheestimationparametervector weresubstitutedintotherecursiveleastsquares
Td(e(z) z 1e(z)))T0

Thediscrete pulse transfer function
formulas.Sotheparametersofthecontrolledobjectcouldbe
identifiedonline.
Withforgettingfactorrecursiveleastsquaresalgorithmformula can be expressed as

u(z)
r rz 1 rz 2
P(k 1) (k)
0 1 2 =
1
(5)
K(k) TP(k 1) (k)
e(z) 1 z

(k) (k 1) K(k)[y(k) (K) (K 1)] T

1 T

where,
r0 Kp(1 T/TI TD/T)
P(k) [1 K(k) (k)]P(k 1)

r K(2T/T) r_1 P D

KT/T r_2 P D

isthe forgetting factor. Its value is selected between 0.95 1 by considering the time-varying parameters,

II. THEDESIGNOFTHELEASTSQUARESALGORITHMPARAMETERESTIMATOR

There are a lot of different model parameter identificationalgorithms,andtheleastsquaresalgorithmisthemostwidelyused identification algorithm in industrial control because ofsmallonlinecomputationandhighstability.Withthegrowthof data, the data saturation of ordinary least squares willappear,andwithalargeamountofcalculations,itwillleadtoa decline in the control of the system. In order to overcomethis phenomenon, the recursive least square method withforgettingfactorwasadoptedfortheestimationofsuperheatedtemperature outerPID controller[13], [14].

The controlled object with Controlled Auto RegressiveMovingAverage (CARMA) modelis expressed as disturbancesandtheorderofthemodel.Kisthegainvector.

Pistheestimationerrorcovariancematrix.

III. POLEASSIGNMENTOPTIMALPREDICTIONSELF-TUNINGCONTROLALGORITHM

For linear system, pole distribution not only has an effectonthestabilityofthesystem,butalsohasagreatinfluenceonthesystemdynamiticperformancessuchasrisetime,overshootandoscillationfrequencyetc.Therefore,aslongaschoose a feedback control law to make the closed-loop polesin the desired position, the closed-loop system performancewill meet the prescribed performance index. This is the poleassignmentdesignmethod [15]. Also in this passage theoptimalpredictionmethodisadoptedtosolvethedelayproblemin the process control.

ByDiophantineequation

$C(z^{-1})/A(z^{-1})$

intheobject

$A(z^{-1})y(k) = z^{-d}B(z^{-1})u(k) + C(z^{-1})\xi(k)$

(6)

modelwhichdescribedin(6)canbedecomposedinto

y(k)issystemoutput,u(k)iscontrolquantity, (k)is

$C(z^{-1})$

1 d $G(z^{-1})$

thenoise,disthedelaytimeofthesystem,

$A(z^{-1})$

and

$A(z^{-1})$

F(z

) z

$A(z^{-1})$

(8)

$B(z^{-1})$

isweightedpolynomialofthecontrolledobject,

where,

$F(z^{-1}) = 1 + f z^{-1} + \cdots + f z^{-d-1}$

$T(z^{-1}) = 1 + tz^{-1} + tz^{-2} + \cdots tz^{-m}$

(16)

□ 1 d□ 1
1 2 m
□(□ 1)□ g□ gz□ 1□ ··· □g z□ n□ 1
(m□ n□ 2)
□G z 0 1
n□ 1
Using (6)and(8), wecanget

G(z□ 1)
y(k□ d)□ C(z□ 1) y(k)□

B(z□ 1)F(z□ 1)

C(z□ 1)

u(k)

(9)
From(15),wecanseethattherearenolagsinclosed–loopsystemcharacteristicequation.Sothepoleassignmentoptimalpredictionself-tuningPIDcontrolsystemcan overcome long-time delay.
Solve(15),andthenwecangettheparametersofPID
□ F(z□ 1)e(k□ d)

y□(k□ d)| k□representsestimationvalueatthetimeof
(k□ d)according to output valueofktime.
The problem now is to find optimal prediction
y*□(k□ d)|k□iny□(k□ d)| k□tomaketheleastprediction
controller.
From the above, the pole assignment optimal predictionself-tuningalgorithmiscomposedofsystemparameteridentificationandpoleassignmentoptimalpredictionalgorithm.The steps can besummarized as follows

- Settheinitialvalue;includemodelinitialparameter□

errorvariance,whichsatisfythefollowingformula

E□y(k□ d)□y*□(k□ d)|k□□ 2
and identification coefficient□ andPetc.

- Samplingthecurrentcontrolledquantityoutputquantityy(k).

u(k)

and

□ E□y(k□ d)□ y□(k□ d)|k□□ 2
(10)

- IdentifythemodelparameterA(z□ 1)andB(z□ 1).
- Using(3),F(z□ 1)andG(z□ 1)canbecalculated.

Using (9)and(10),wecan get

- Using(6),theexpectedoutputy*□(k□ d)| k□

calculated.
canbe

* G(z□ 1)

- ThecontrollerparameterS(z□ 1)and
R(z□1)
canbe

y□(k□ d)|k□□ C(z□ 1) y(k)
□B(z□ 1)F(z□ 1)
C(z□ 1)

u(k)
(11)
calculatedbyusing(12).

- Using(10),thecontrolledquantityobtained.

u(k)

canbe

- u(k)
substituted into equation (1),
y(k)
canbe

Inadigitalsystem,thePIDcontrolleralgorithmwithdigitalfilteriscommonlyused.So(5)canbewrittenas
obtained.

- Returntothe second step.

□ r□ rz□ 1□ rz□ 2

u(z1)□0 1 2 e(z□ 1)(1□ z□ 1)(1□ sz□ 1)

1

12)

IV. TEMPERATURECONTROLSYSTEMOFPOWERSTATIONBOILERSUPERHEATEDSTEAM

Sothe controller isdesigned according tothediscretePID
controller(12).
Themainsteamtemperaturecontrolofthepowerstationboileris one ofthe important parameters whichwillconcern

where,
□yr
□ y*□(k□ d)|k□□R(z□ 1)□ S(z□ 1)u(k)

S(z□ 1)□ (1□ z□ 1)(1□ sz□ 1) 1
R(z□ 1)□ r□ rz□ 1□ rz□ 2
(13) 0 1 2

unitsafetyandeconomicoperation.Commonlycontrolmethods are double-loop control system using differentialcompensation signal and cascade control system using theconventional PID controller. But the controlled object hascharacteristics of great inertia and long-time delay. For thesecontrol methods it is difficult to achieve the best controleffect.Theactualsituationshowsthatalthoughsomepower

Using(6),(9),(11),(13),thepoleassignmentoptimal predictionself-tuningcontrolsystemoutputcanbewrittenas

$$y(k) = \frac{z^{-d}B(z^{-1})R(z^{-1})}{S(z^{-1})A(z^{-1}) + B(z^{-1})R(z^{-1})} y_r(k) \quad (14)$$

$$+ \frac{R(z^{-1})F(z^{-1})B(z^{-1}) + S(z^{-1})C(z^{-1})}{S(z^{-1})A(z^{-1}) + B(z^{-1})R(z^{-1})} e(k)$$

station have adopted Distributed Control System (DCS), thecontrol quality of steam temperature is still not very ideal.The steam temperature will deviate from the set value abovemorethan8℃ evenwhentheloadchangeswithonly2%MCR/minrateforsomepowerstations.Sooftenthemain steamtemperatureisoftencontrolledbymanualoperation.It leadtothesteadystatetemperaturerangeexpandedtothe scopeof±6℃,thiswillreducetheeconomicoperationoftheunitandincreaselabor intensityof operator.

From(14),theclosed-loopsystemcharacteristicequation is

$$S(z^{-1})A(z^{-1}) + B(z^{-1})R(z^{-1}) = C(z^{-1})T(z^{-1}) \quad (15)$$

$T(z^{-1})$ isthe expected characteristic polynomial assignment.

A.The ModelofSuperheated SteamObject

Thispassageisbasedonthesuperheatedsteamsystemof Anhui power station #2 boiler (600MW subcritical boiler).Themaincontrolsystemofsteamtemperatureadoptscascadecontrolsystem.TheouterloopusesPIDcontroller, andtheinnerloopusesPcontroller.Thestructureisshownin Fig.1. θ_{t1} and θ_{t2} isthetemperaturetransmitterslope coefficient.$t_1$istheoutlettemperatureofdesuperheater.t_2 istheoutlettemperatureofsuperheater.Thecontrolledobject iscomposedofspraywateradjustingvalve,desuperheater andsuperheater.Thedegreeofopeningofthespraywater adjustingvalveistheinputsignalofthecontrolsystem,andtheoutlettemperaturetofthesuperheateristheoutput

transfer function of forward screen A is $\frac{0.482}{(1+27.74S)(1+28.65S)}e^{-37S}$.Thetransferfunctionofbackward screenis $\frac{0.576}{(1+155.59S)}e^{-46S}$.TheparameterofinnerPIDKp is 50. Thus we can get the main loop model 3.75

(1□ 26.19S)(1□ 27.74S)(1□ 28.65S)(1□ 155.59S)
□ 98S
.
2
signal.
Thecontrolled objectconsists of two parts.

- With the opening degree of the spray water adjustingvalveasinputsignal,thedesuperheateroutlettemperature$t_1$asoutputsignal,thispartiscalled leadingsegment.
- Withtheoutlettemperature$t_1$ofdesuperheaterasthe

Thispassagewillusethesuperheatedsteamtemperature
model as the simulation research object. Superheater steamtemperature control scheme in the paper adopts the cascadecontrol system which combined outer master PID with poleassignment optimal prediction algorithm, it don't change theinnerloopcharacteristicsofthetraditionalcascadePIDcontrolsystem.Thegeneralizedcontrolledobjectmodelisasshown in Fig. 2.
inputsignal,theoutlettemperaturet_2

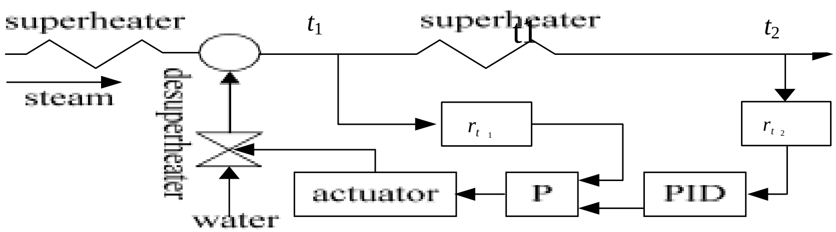


Fig.1.Steamtemperaturecascadecontrolsystem.

ofsuperheater as
outputsignal.This partis calledinertsegment.

The boiler superheater steam temperature identificationmodel with a load of 550MW is given in reference[16]. Inwhich we choose the model of desuperheaterA, forwardscreen,andbackwardscreenasanexample.Thetransfer functionofprimarydesuperheaterAis
0.270

(1□ 26.19S)²
□ 15S.The

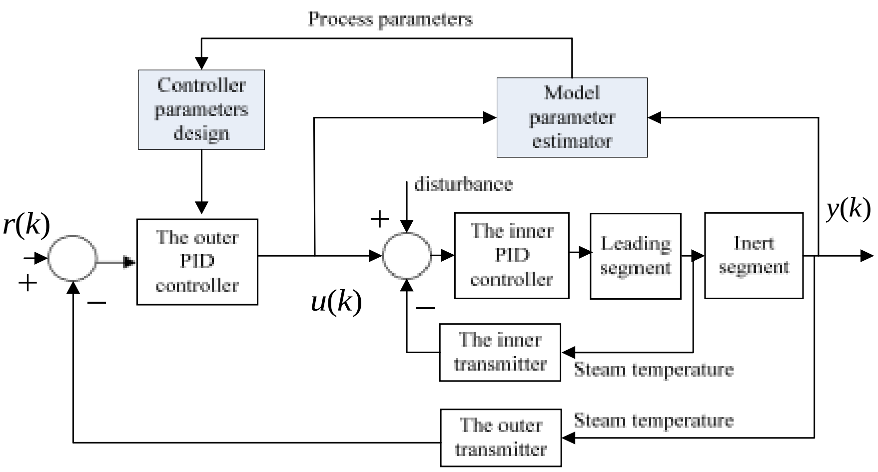


Fig.2.Thestructureofsuperheatedsteamtemperaturecascadesystem.

B.The Algorithm Flow BasedPoleAssignmentOptimalPrediction
Thealgorithmflowbasedpoleassignmentoptimalpredictionis shown in Fig. 3.
a_1□ □ 0.39,b_0□ 2.28.
Accordingtotheviewpointofpoleplacement,takethesecond-ordersystemclosedlooptransferfunctionstandard
□^{2}

C.Simulation Study
form
$G_n(s)$□
n
(s^2□ 2□ □ s□ ^{2}□)
$_n$ $_n$
asthe target. So the

Inordertofacilitatesimulation,takethecombinationofthefeedbackcloseloopofleadingsegmentandinertsegment
discrete characteristic polynomial is
T($z^{□1}$)□1 □2$e^{□□□}$n^{T}cos □

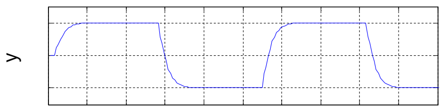
asthegeneralizedobject,andadoptasub-optimalreductionmethod[17]withtimedelaysystemtosimplifythe
n
T z□ ^{1}□e□ ^{2}□ □nT$_z$□ 2 $\sqrt{1-\xi^2}$
, □n
is undamped natural

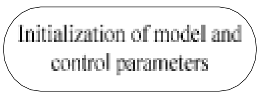
generalizedobject.Atthelastwegettheequivalentapproximatemodel (typical first-orderinertiaobject withpuretime delay)
oscillationfrequency,□ isdampingratio.
When□ □ 0.707,itistheoptimaldynamicsecond-orderresponsemodel. Theprincipleofchoosingpolynomial

G□ 3.75
e□ 170S
C($z^{□1}$)
isbasedonreference[16]. Theshockwhichis

170.5S□ 1
Theparametersofdiscretemodeltobeidentifiedare
causedbymutationsintheinputsideshouldbeavoided.

ThenwechooseC($z^{□1}$)□ 1□ 0.5$z^{□1}$□ 0.1$z^{□2}$.
Theinitialsimulationparameterssettings,theforgetting
self-tuning PID controller has better dynamic and staticcharacteristicthan conventionalPID controller.
factormatrix
□ □ 0.95
the estimation error covariance 10
P□ 10^6I initial model $_0$
parameters$_1$□ □$_0$ [ab]^{T2}□ [0.0010.001]^T.





-10

2

0

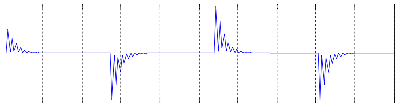
-2

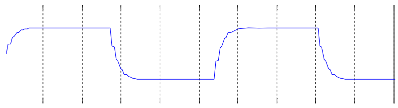
5

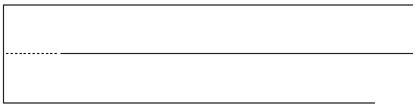
0

-5

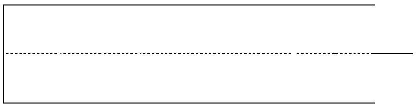
050100150 200 250 300 350 400 450 500
t/min







050 10015 200250 35 40 45 50
0 300 0 0 0 0
t/min



050 10015 200250 35 40 45 50
0 300 0 0 0 0
t/min

Fig.5.Thesimulation.

12

10

8

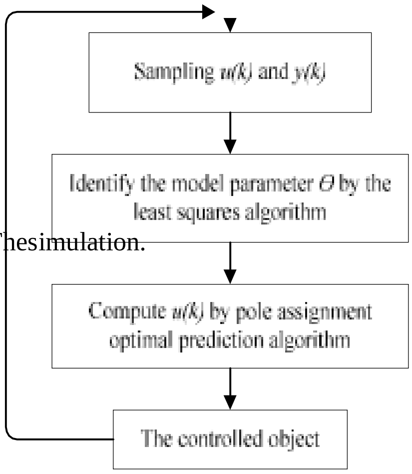


Fig.3.Thealgorithmflowchartofpoleassignmentoptimalprediction.
Thesimulationresults areshown below:

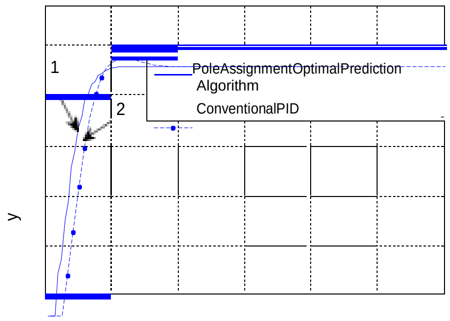
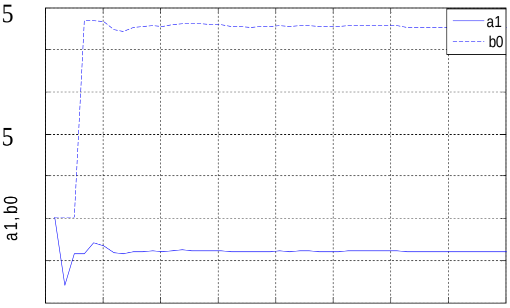
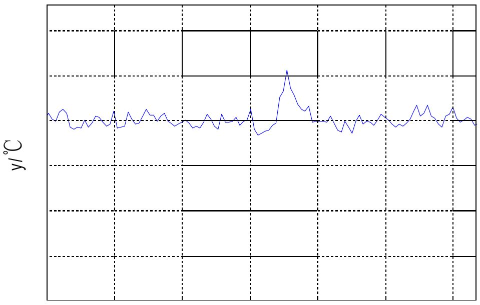


Fig. 4 is the simulation result of the object parameteridentification process. We can see that at the beginningof the identification process, the result is not accurate.After a period of time identification, the parameters oftheobjectstabilizedgradually.Sowecangettheaccuratemodel parameters.

2000 4000 6000 8000 10000 12000
t/s
Fig.6.Thecomparisonofsimulationcurves.

2.5
2
1.5
1





540
535
530
525
0.5
0
-0.5
-1

0 1000 2000 3000 4000 5000 6000 7000 8000
t/s
Fig.4.Modelparametersidentificationsimulation.

100 150 200 250 300 350 400
t/min
Fig.7.Steady-stateanddynamicsimulationresultofpoleassignmentoptimalpredictionalgorithm.

- Fig.7isthecurveofsimulatingtheactualboiler.On260minutes,10%disturbancewasaddedtothesystem

- Under the ideal conditions, the simulation curve of theboilersuperheaterwithpoleassignmentoptimalprediction algorithm is as shown in Fig. 5. We can seethat the system has good response characteristics, suchasfastadjustmentspeed,goodfollowingfeaturetoinputsignal, effective in suppression of overshoot.
- FromFig.6,curve1isthesimulationresultofadoptingpole assignment optimal prediction algorithm. Curve 2is the simulation result of adopting conventional PID.We can see that the rise time of curve 1 is less than therise time of curve 2. There is almost no overshoot incurve1. But for curve 2, there is about 8% overshoot.Therefore,thepoleassignmentoptimalprediction

load, we can see that the output temperature deviatesfrom the set value at 5℃, and then return to the settemperature value about 540℃ again. The result meettheactualproductioncontrolrequirementthatthesuperheatedsteam temperaturefluctuationrangeindynamicsituationisabout±6℃,atsteady-stateconditionis about ±2℃.

- Fig. 8 is the simulation curve of adopting conventionalPIDcontroller.Whendisturbancewasaddedtothesystem load, the output temperature deviates from theset value at 9 ℃, and then return to the set temperaturevalueabout 540℃ .Atsteady-statecondition,thesuperheatedsteamtemperaturefluctuationrangeis

about ±4℃.The control effect of adopting conventionalPID controller is notideal.

555

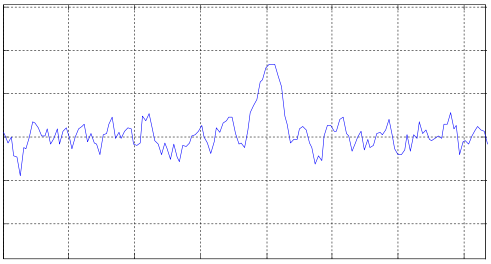
550

545

y/℃

540

535



530

50 100 150 200 250 300 350 400

t/min

Fig.8.Steady-stateanddynamicsimulationresultofconventionPIDcontroller.

CONCLUSION

With more and more power boiler units develop to highcapacity,multipleparameters,andhighefficiency,theproductionsystembecameincreasinglycomplex.Systemcoupling, time-variation, nonlinear become more prominent.The superheated temperature of the steam superheater is atypicalcontrolobjectofnonlinear,long-delay,andgreatinertia. Although there are many new control methods forpower steam temperature, the PID algorithm is still widelyused because of its simple control structure and algorithm,easy to implement, and good applicability. In this paper, thePIDcontrollerparametertuningmethodbasedonpoleassignment optimal prediction algorithm is proposed. Themodel of superheated steam temperature is also simulated inthispassage.Theresultofsimulationverifiestheeffectivenessofthepoleassignmentoptimalpredictionalgorithm.

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