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2020 3rd World Conference on Mechanical Engineering and Intelligent Manufacturing (WCMEIM)

Reviewofresearchonchatterstabilityinmillingof thin.walledparts

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| HaoLiu  schoolofMechanicalandAutomotiveEngineering  shanghaiUniversityofEngineeringscience  shanghai,China  17865917832@163.com | YufengZhou  schoolofMechanicalandAutomotiveEngineering  shanghaiUniversityofEngineeringscience  shanghai,China  zhouyufeng0318@163.com |

***Abstract*—Milling** **is** **widely** **used** **in** **the** **processing** **of** **thin-** **walled****parts****with****weak****rigidity·****As****the****chatter****during****the****milling** **of****thin-walled****parts****will****cause****processing****quality****problems**，**some** **measures** **need** **to** **be** **taken** **to** **suppress** **chatter·** **This** **paper** **describes****the****research****overview****of****chatter****stability****during****milling·** **According****to****the****physical****conditions****of****flutter****format**ion，**flutter** **can** **be** **divided** **into** **vibration-type** **coupled** **flutter**， **friction-type** **flutter**，**and****regenerative****flutter·****In****order****to****solve****the****problem****of** **flutter**， **the** **flutter** **is** **firstly** **modeled** **dynamically**， **and** **then** **the** **flutter** **model** **is** **solved** **by** **the** **frequency** **domain** method， **the** **discrete****method**，**etc**·，**and****the****stability****domain****lobe****diagram****can** **be****drawn·****In****additio**n，**the****research****on****flutter****prediction**，**flutter** **stability** **analysis**， **flutter** **monitoring** **and** **flutter** **suppression** **is** **summarized** **and** **analyzed·** **The** **research** **and** **methods** **on** **the** **flutter** **problem** **are** **continuously** **proposed**， **which** **effectively** **promotes** **the** **processing** **efficiency** **and** **surface** **quality** **of** **thin-** **walled****parts·**

***Keywords-thin-walled*** ***parts;*** ***milling*** ***chatter;*** ***stability*** ***analysis;*** ***chatter*** ***suppression***

I. INTRoDUCTIoN

Thin.walledpartshavesmallweightandhighstrength,and are common in aerospace structures. Milling, as a common processingmethod,hastheadvantagesofsmallmillingforce andwideprocessingrange,andiswidelyusedintheprocessing of thin.walled parts. Due to the complex structure of thin. walledparts,highmaterialremovalrateandlowlocalrigidity, chatter vibration is prone to occur during milling. when the chip thickness is generated during the machining process, chatteringiscausedbytheself.excitedmechanism[1],which manifests as the vibration between the workpiece and the cuttingtool,resultinginpoordimensionalaccuracyandsurface finishoftheworkpiece,andeventhedamageofthecuttingtool oreventhemachinetoolinseriouscases[2].Therefore,inthe processingofthin.walledparts,solvingtheproblemofmilling chatter has become the focus of research by domestic and foreignscholars.

scholars' research on chatter in thin.walled parts milling mainlyfocusesonchatterprediction,stabilityanalysis,chatter monitoring and chatter suppression. Construct milling chatter modelandstabilitylobediagramfromtheprocessingofthin. walledpartstofindthemainfactorsaffectingchatter;construct chatterstabilitydomain,selectappropriatecuttingparameters inthestabilitydomaintosuppresschatter,andatthesametime the real.time online identification and evaluation of milling chatterarerealizedthroughthefluttermonitoring.Inthispaper,

the problem of milling chatter of thin.walled parts is summarizedfromtheaspectsofmodelingandprediction,on. linemonitoringandsuppression.

II. ANALYsIsoFMILLINGCHATTERMECHANIsM

Theresearchmethodsfortheanalysisofchatterstabilityin themillingprocessaremainlytoconstructamodelofmilling chatter, predict the stability boundary of the milling process, determinethestablemillingzoneandtheunstablemillingzone, and select the appropriate milling parameters from the established stability flap diagram to suppress the chatter and improvethemillingqualityandefficiency.

*A.* *Theoretical* *research* *mechanism*

According to the formation method of flutter, it can be dividedintothreeforms,namelyvibration.typecoupledflutter, friction.typeflutterandregenerativeflutter[3].Amongthem, regenerativechatteristhemainformofmillingchatter,andit is a common self.excited vibration in the machining process. whenthetooliscuttothevibrationmarksonthelastresidual surface of the workpiece, the dynamic milling force will fluctuate, and the phase difference between the two adjacent vibration marks on the workpiece will cause regenerative chatter.Therefore,thechatteratanymomentisnotonlyrelated tothecurrenttooldeflection,butalsorelatedtothestateofthe cuttingsystematthepreviousmoment.Duetotheexistenceof the regenerative effect, the regenerative flutter model is generallydescribedbyadelaydifferentialequation.

*B.* *Stability* *lobe* *diagram* *domain*

Bysimulatingthemillingprocess,Lietal.[4]establisheda milling force model and analyzed the lobe diagram in the stabilitydomain,whichcouldbeusedtooptimizethemilling parametersandprovideareferenceforinhibitingthechatterin the milling process. Fei et al. [5] proposed a dynamic model suitable for predicting chatter during the processing of thin. bottomedflexiblebag.shapedstructures,andperformedmodal analysis on it to obtain system parameters. semi.discrete method was used to draw stability lobe diagram, so as to determineappropriatecuttingconditionswhenmillingthethin bottomofflexiblechamberstructure.Huangetal.[6]proposed amethodforcalculatingthereliabilityofregenerativechatter stability during milling, and used the full.discrete method to drawthemillingstabilitylobediagram.Mietal.[7]simplified themachinetool.tool.workpiecesystemintoavibrationsystem asshowninFig.1,establishedadynamicmathematicalmodel

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formillingprocessing,andcalculatedanddrewastablevane diagrambyanalyticalmethod.Basedonit,amillingparameter optimizationmodelthatcanobtainthebestspindlespeed,radial feedandaxialfeedwasproposed.

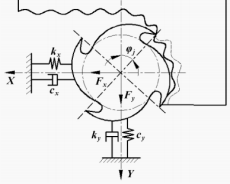


Figure1. Millingvibrationsystemmodel

○u et al. [8] proposed a three.dimensional stability lobe diagramofthin.walledplatemillingbasedonatime.domain fluttermodel.sinceahigherfeedratewillproduceagreater millingforce,asthefeedpertoothincreases,thesurfacequality ofthin.walledpartswilldecrease.Duringprocessing,thebest millingparameterscanbeselectedaccordingtothediagramto avoid vibration and increase productivity. Campomanes [9] proposedanimprovedmillingtime.domainmodeltosimulate the vibration cutting conditions under a small radial cutting width,andtheimprovedkinematicsmodelcansimulatevery smallradialimmersion.Themodelcanpredictthemillingforce, thesurfacefinishoftheworkpieceandthevibrationstability, soastoaccuratelysolvethenonlinearinfluenceofthemodeling.

III. PREDICTIoNoFMILLINGsTABILITY

Ifthechatterthatmayoccurinthemillingofthin.walled parts can be predicted in the process planning stage, the machiningprocessparameterscanbeimprovedinadvanceto avoidchatterduringthemillingprocess,therebyimprovingthe millingefficiencyandmachiningquality.

Budak et al. [10] proposed a method for predicting the dynamicsoftheworkpieceintheprocess.Themethodisbased on the dynamic modification of the structure using thefinite element model of the workpiece, and the simulation was verifiedbyexperiments.Jinetal.[11] established astability prediction model, which takes into account the dynamic characteristicsofthemillingprocess,predictsthestability of thethin.wallmillingsystemthroughthefull.discretemethod, and establishes a three.dimensional stability vane Figure, optimize processing parameters and improve processing efficiency. Ding et al. [12] proposed the relative dynamic behavior between the tool subsystem and the workpiece subsystem. According to its dynamic characteristics, the frequency domain method was used to predict the critical conditions of system stability, and the time.varying critical stability of chatter Conditions, a three.dimensional lobe diagramofflutterisestablishedtoshowthechangesinflutter conditions.

Yangetal.[13]proposedacomprehensivedynamicsmodel for predicting sLD in peripheral milling of thin.walled workpiece with curved surfaces. The model and method can accuratelypredictthestabilityofthin.walledplatesandcurved surface milling. Lyu et al. [14] combined the semi.discrete methodtopredictthestabilityofmillingmachiningwiththe changeinthemeshingconditionofthetoolworkpiececaused by the cavity milling path, and proposed and verified the validityofthepredictionofthestabilityofcavitymachining.In addition,themethodbasedonmatrixperturbationtheorycan also be effectively applied to the prediction of modal parameters inthe finishingprocess of thin.walledparts [15]. sunetal.[16]consideredtheforce.induceddeformationeffect intheinteractionofstaticanddynamicsystems,andcombined the stability prediction model with deformation, multi.point contactstructuredynamics,materialremovalandtime.varying multi.modaldynamicparameters.Thesystem's3D.sLDmakes accuratepredictions.Aneffectivedecomposition.condensation methodproposedbyYangetal.[17]hasashortcalculationtime andhashigheraccuracythanthepreviousmethod,butitwill alsohavegreatermemoryconsumption.

IV. CHATTERoNLINEMoNIToRING

There are some non.linear problems in the processing of thin.walled parts, which make it difficult to predict the machiningvibration.onlinemonitoringofthemillingprocess canobtainthestatusofthetoolandworkpieceinrealtime.This madeitpossibletostudythevibrationstateofthin.walledparts under the action of alternating cutting forces during milling. therefore,chattermonitoringisanimportanttasktoimprovethe productivityandpartqualityinthemachiningprocess.

A vibration identification method for end milling was proposed in 2015. The vibration signal is adaptively decomposedusing theEEMD method, which can effectively avoidtheinterferencetotheoperator[18].Theauthorproposed a vibration detection method based on the synchronous compressiontransform（ssT)ofthesoundsignalthefollowing year[19].Thismethodcaneffectivelymonitoronlinechatter during high.speed milling. Liu [20] et al. used PVDF piezoelectricfilmsensors,andalsoproposedamethodforon. line monitoring of vibration in the milling process of thin. walledpartswithoutinterference.Itcanalsoidentifydifferent processingstagesinthemillingprocessandfacilitatereal.time decision.making on the processing process. The evaluation index based on the energy entropy of the wavelet packet establishedbyZhangetal.[21]canalsoeffectivelyidentify the stabilityandvibrationstateofmilling.

In addition, the use of the dynamic characteristics of the workpiececanbetteridentifyregenerativechatter[22],andthe chatterdetectionthresholdbasedonchangesinthegeometryof the workpiece, tool path and dynamic characteristics can effectively identify chatter. Recently, a dynamic milling stabilitypredictionmethodforthin.walledpartswithatime. varyingstiffnesssystembasedonthecombinedmethodofVPC and Vss was proposed [23]. This method can predict the milling stability of thin.walled parts with a time.varying stiffnesssystem.

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V. CHATTERsUPPREssIoNsTRATEGY

In order to suppress chatter during the milling process of thin.walled parts with weak rigidity, the methods adopted include stiffness lifting, damping lifting and cutting process optimization.

*A.* *Stiffness* *improvement* *strategy*

Compared with the traditional uniform allowance machining, non.uniform allowance machining in thin.walled partscanimprovethemachiningrigidityoftheworkpieceand ensurethestabilityofthecuttingprocess[24].Thereby,chatter vibrationcanbesuppressed,andtheprocessingefficiencyand surfacequalitycanbeimproved.Matsubaraetal.[25]proposed apivotmechanism,whichusesthesurfacesupportofthepivot mechanismtohaveabettereffectonfluttersuppression.Jiang [26] proposed an auxiliary support method based on magnetorheological fluid, dynamic model and simulation prediction model in view of the weak rigidity and complex structure of thin.walled parts. Through this method, the best parametersofthemagnetorheologicalfluidclampcanbefound, whichcaneffectivelyimprovetheprocessingqualityofthin. walledparts.

*B.* *Damping* *promotion* *strategy*

BudakandAltintas[27]proposedananalyticalmethodto solvetheproblemofchatterstabilityinendmillingoperations inordertosuppresschatterduringmilling.Thismethodtakes into account structural dynamics in the cutting plane and changesalongtheaxialdirection.Bymodelingtheworkpiece and the tool as a multi.degree.of.freedom structure, a comprehensiveexpressionofthedynamicmillingforceisgiven. Yang et al. [28] proposed a damping vibration reduction scheme based on viscoelastic material, damping layer, constraint layer and mass layer, which can be applied to the five.axismillingofs.shapedthin.walledparts.Ithasobvious vibrationreductioneffectandstrongadaptabilityintheprocess of processing. A method to reduce the chatter of thin.walled partsby immersing themillingsystem in a viscous fluidhas beenproposed[29].Undertheconditionofviscousfluid,the damping of the system is significantly increased. Tests show thatthismethodcaneffectivelysuppressthevibrationofthin. walledworkpiecesandreachahigherstabilitylimit.

*C.* *Cutting* *process* *optimization*

seguyetal.[30]conductedatestonathree.axishigh.speed millingcenterasshowninFig.2,andtheresultsshowedthat the milling process can be stabilized by increasing the amplitudeofthespindlespeedchange,andthefrequencyofthe spindlespeedchangehasnoeffectonthedynamicbehavior. Zhang et al. [31] established the time.delay differential dynamicsmodeloftheflexibletool.

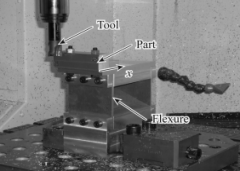


Figure2. Three.axisexperimentaldevice

rigid workpiece dual.degree.of.freedom milling process system,andobtainedthestabilitylobediagramtopredictthe stable cutting process parameter domain through the full. discretemethod,basedonthereasonableselectionofprocess parameters,thefluttercanbeavoidedandtheforcedvibration canbesuppressed.

VI. CoNCLUsIoN

Inthispaper,theresearchofchatterproblemintheprocess ofthin.walledpartsmillingissummarized.Vibrationcoupling, friction,andregenerativefluttertheorieshavebeenrelatively mature. Methods such as frequency domain method, time domain method, semi.discrete method, and full.discrete methodhavebeenappliedtostabilityanalysis.Inrecentyears, withtheresearchonchatterproblems,therearemoreandmore methodsforchatterprediction,onlinechattermonitoring,and chatter suppression. From linear to nonlinear problems, from simplethin.walledpartstocomplexcurvedthin.walledparts, all advances in theories and methods are finally applied in production,whichcaneffectivelydealwithaseriesofproblems caused by chatter and improve the efficiency and quality of thin.walled parts processing. At the same time, as research continuestoprogress,itwillbeagreatprogresstointegrate the chatter prediction, real.time monitoring with the suppression andeventhesurfacequalitymonitoringofthin.walledparts.

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