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Parameteric Study of Face andShoulder Cylindrical Grinding Process

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ABSTRACT
Grinding is a machining operation that improves the work-piece's surface quality and dimensional precision. Depth of cut, work-piece traverse speed, grinding wheel grain size, number of passes, material removal rate, material hardness, and grinding wheelrotational speed are among the process characteristics that affect the cylindrical grinding operation. Because increasing bothperipheralworkpiecespeedandwork-piecefeedhasanegativeinfluenceonsurfaceroughness,whilehighmaterialremovalcausesareductioninsurfaceroughness,hence,peripheralworkpiecespeedandwork-piecefeedareconsideredascrucialparameters.Oneofthemostpopularmachiningmethodsusedinfinishingoperationsis cylindricalgrindingprocess.Intermsofquantityandquality,themetalremovalrateand surfacefinishare themostcriticaloutputresponsesinthemanufacturingprocess.
The fundamental goal of this research is to investigate the critical process variables that induce grinding burn and influence thequality of face and sholuder cylindrical grinding. This research identifies the major grinding factors, which are subsequentlyinvestigated using the VBA Excel solver. Workpiece feed rate and workpiece peripheral speed were used as decision variables,depth of cut, speed ratio, aggressiveness, and chip thickness were used as constraint variables, and the productivity indicator Qw'(materialremoval rate)wasusedasa target. Theoverallmachiningtimehasbeenreducedby67.85percentasaresultoftheoptimisedparametersobtainedfromtheVBAexcelsolver tool. The target has achieved by the definition of a standard set of process optimized parameters that creates a surfaceconsistentto accuracy,integrityand damagetolerancerequirementsand byarobustcontrolofttheseparameters.

I. INTRODUCTION

Grinding is an important technology in the metal manufacturing process because it ensures the needed surface finish when othermanufacturingprocessesfailtosatisfyproductspecifications.Grindingisusedinthelastphasesoftheproductmanufacturingcycle,when the machined part's value is already high and errors can be costly. Grinding affects physical layer qualities such as residualstress, hardness, and microstructure during the material removal process, putting the part surface layer at danger of heat damage.Grinding is a manufacturing process with a high level of added value. Companies that produce high value in manufacturing havegreatfinancialperformancein today'sglobalmanufacturer competition,thanksto their highqualityreputation.
Howevertheymustconstantlyimprovetheirperformancesfirstofallintermsofqualityanddeliveringtimetomaintainleadershipin their business. This becomes possible only innovating, inventing, investing in Research and Development and last but not leastinvestinginpeople knowledge.
Thefirstwasathoroughexaminationofthegrindingprocess,aswellasknowledgeofaeronauticalproducts,particularlygears;thesecondwasameticulousdatacollectionofthecurrentgrindingprocessfromtheIndustries;thethirdwasathoroughanalysisofthegathereddata;andthefourthwasamulti-prongedapproachtoimprovethecurrentprocess,takingintoaccountnotonlythegrindingbutalsotheneedsofthe technologists,assistingtheminthedefinitionof grindingparameters.

GrindingProcess

Abrasives have been used for shaping for over 2000 years. Sharpening early knives, tools, and weapons was done with abrasivestones.Abrasiveshavebeenusedsinceancienttimestocutandshaperocksandstonesfortheconstructionofbuildingsandedificessuchasthepyramids.Abrasiveswerealsousedtocutandpolishgemstones.Abrasivesarestillusedinawiderangeofapplicationstoday, and the abrasives industry is responsiblefor the production ofmany modern mechanical parts. Even in the beginning,grindingwasa finishingprocessusedonproductsnearingthemostvaluable stageofproduction.
Grinding was invented as a metal manufacturing process in the nineteenth century, and it was crucial in the development of tools,aswellastheproductionofICengines,gearboxes,

transmissionsystems,andeventuallyjetengines,astronomicalinstruments,andother electronicscomponents.

Inmodernproduction,thephrase"grinding"referstomachiningwithhigh-speedabrasivewheels,pads,andbelts.Grindingwheels areavailable inawide rangeofshapes, sizes, andabrasivekinds.

Grinding was recognised as a strategic process for high-technology applications in the second part of the twentieth century.Manufacturers of aero-engines and missile guidance systems, for example, discovered that grinding was the key to achieving therequired quality. In the latter half of the twentieth century, this resulted in fast development. A tendency toward hard ceramicmaterialshasemerged inmoderntechnology,posingnew manufacturingconstraints.

II. LITERATURE REVIEW

Theliteraturereviewfocusesonresearchthat hasbeenpublishedinlinkedjournalsandarticles.Theliteraturediscussestheeffectsofinputandmachiningparametersonoutputresponseparametersusingoptimizationtechniquesforthecylindricalgrindingprocess.

L. P. George et al. [1] “Experiments using a cylindrical grinding machine were carried out in order to better understand the cuttingmechanisms.Toinvestigatetheimpactofcuttingspeed,depthofcut,andmaterialhardnessonsurfaceroughnesswhilekeepingallother variables constant. To establish an empirical relationship between the obtained surface roughness value and process parametersExperimentswerecarriedoutonaMILANORICENRUM 1cylindricalgrindingmachineequippedwitha L9orthogonalarray.

D. Pal et al. [2] “Surface roughness was investigated experimentally using cylindrical grinding process parameters. The tests werecarried out on a universal tool and cutter grinding machine equipped with a L9 orthogonal array. Material hardness, work piecespeed, and grinding wheel grains are all input machining variables. Die steel (EN24, EN31) was employed as the work componentfor this experiment. The Taguchi method was utilised to optimise the parameters of the process. The optimal value of surfaceroughnessforthecylindricalgrindingprocessisfoundtobe1.07Ra.Whenthespeedisincreasedfrom100to160rpm,thesurfaceroughnessdiminishes.Surfaceroughnessdecreaseswhen grinding wheelgrainsareadjusted fromG46 to G60.”

K.Mekalaetal.[3]“Proposedcylindricalgrindingmachineexperimentsonaustenitestainlesssteelrod(AISI316).Cuttingspeed,depthofcut,andfeedrateareallinputvariables.TheL9orthogonalarraywasutilisedinaTaguchidesignofexperiment.ANOVAand the S/N ratio are used to optimise the experiment. Metal removal rate and surface roughness are the output parameters. TheworkpiecewasmadeusingAISI316roundrodswithadiameterof50mmandalengthof70mm.Cuttingataspeedof560m/min,withadepthofcutof0.05mmandafeedof0.130mm,metalwasremoved.Cuttingspeedisshowntobethemostimportantfactor,whereasdepthofcutisbetterfor grindingresults..”

M.Melwinetal.[4]“Usingacylindricalgrindingmachine,performedexperimentsonOHNSsteel(AISI0-1)rounds.Thesurfacequality of OHNS steel will be investigated in three levels using a L9 orthogonal array. The input parameters are work speed, depthofcut,andnumberofpasses,whiletheresponseparameterismaterialremovalrate.Theworkmaterialwas OHNSsteelroundbarswith a diameter of 25 mm and a length of 70 mm. During the trial, the best parameters for metal removal rate of OHNS steelcylindricalroundswere 0.02mmdepthofcut, 150 rpmworkspeed, and 1pass.”

N.Kumaretal.[5]“UsingtheTaguchitechnique,theinfluenceofoptimisedmachineparametersonsurfaceroughnessincylindricalgrinding for C40E steel was examined. The L9 orthogonal array is used to optimise the input process parameters of work speed,depth of cut, and feed during the experiment. MITUTOYO surf test SJ210 surface roughness tester is used to measure surfaceroughness. Grinding speed 210rpm, depth of cut 0.04mm, and feed 0.11mm/rev were used to produce experimental findings forminimalsurface roughness.The obtained optimalminimum surface roughnessis0.238m.”

III. METHODOLOGY

1. Study identifies the essential grinding factors, which are then optimized using VBA Excel tool for zero scrap during the CNCcylindricalgrindingprocess.
2. The idea is to use the optimal parameters obtained from the VBA Excel tool to discover the underlying cause of grinding burnusing two variables Peripheral workpiece speed and feed rate and others are best parameter setting that ensures maximumproductivitywithinsafelimits(depthof cut, speed ratio, aggressivenessand chipthickness).

IV. RESULTS AND DISCUSSION

Currentprocessinputparametershavebeenplottedinsomegraphs.

In the industries rough grinding is more similar to semi-finish grinding than literature rough grinding because of their parameters,thus they are classified in a unique range called rough/semi-

finish grinding. Finish grinding has different parameters, thereforegrindingoperationsare basicallyclassifiedintwoclassesofrangeparameters.
A machining operation is the elapsed time during which the grinding wheel removes a certain material overstock, obtaining finalphasepartdiameter ±tolerancesasrequiredbyoperationsheetaccordingto product drawing.

Grinding operations performed in multiple machining steps are planned to remove the material overstock in different percentages.Great percentage of material overstock has to be removed in machining step1, and just a little remaining percentage is removed innextmachiningsteps(classified as“othermachiningsteps”,usedto getbettersurfacefinish).

Fig 1 is the 3D plot of depth of cut values (ae on Z axis), with respect workpiece diameter and workpiece peripheral speed,respectivelyfor rough/semi-finishingandfinishingoperations.

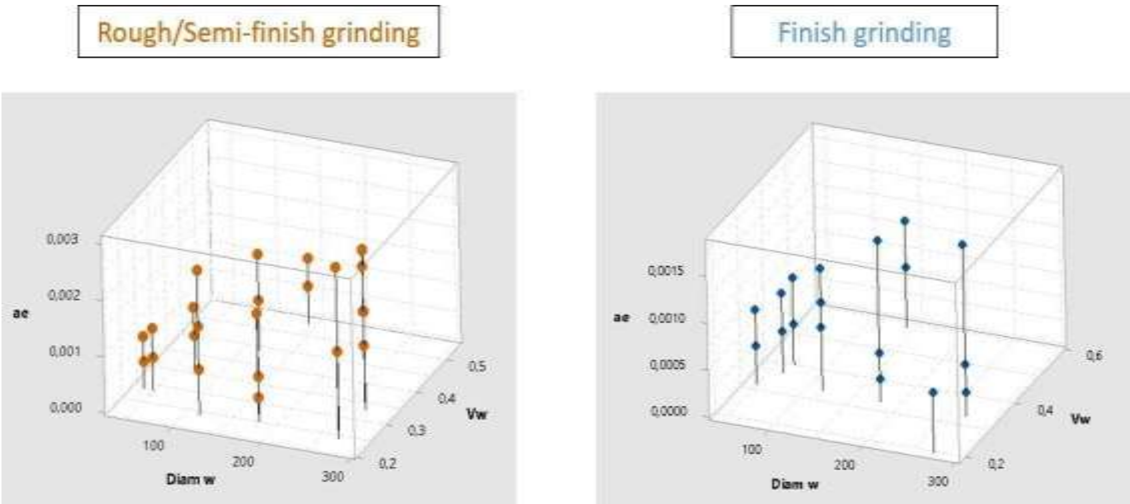

Fig.1 3Dplotofdepthofcut(mm/rev)

Moreover,aninterpolationofthesedatathrua3Dsurfaceplot(Fig.1)hasbeenusedtogiveaneasierinterpretationoftheZvaluesthatismore or lessflat.

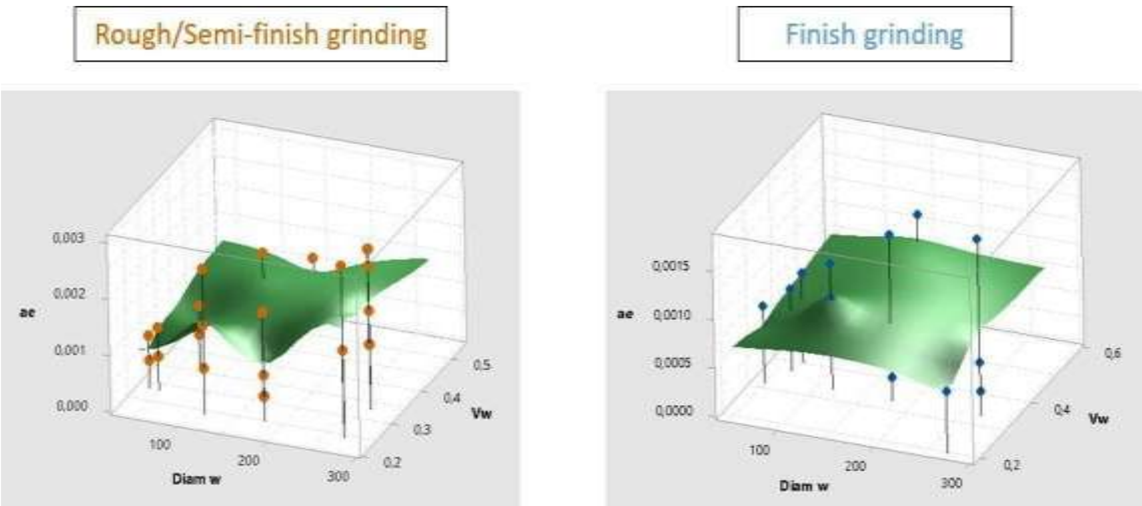

Fig.23Dsurfaceplotofdepthofcut(mm/rev)

Results confirm that feed rate is different with respect different diameter workpieces, but the depth of cut is more or less constantconsideringalsomachiningsteps.Thecurrent safetyrangefordepthofcutto beappliedonrough/semi-finishgrindingisshowninFig.2.

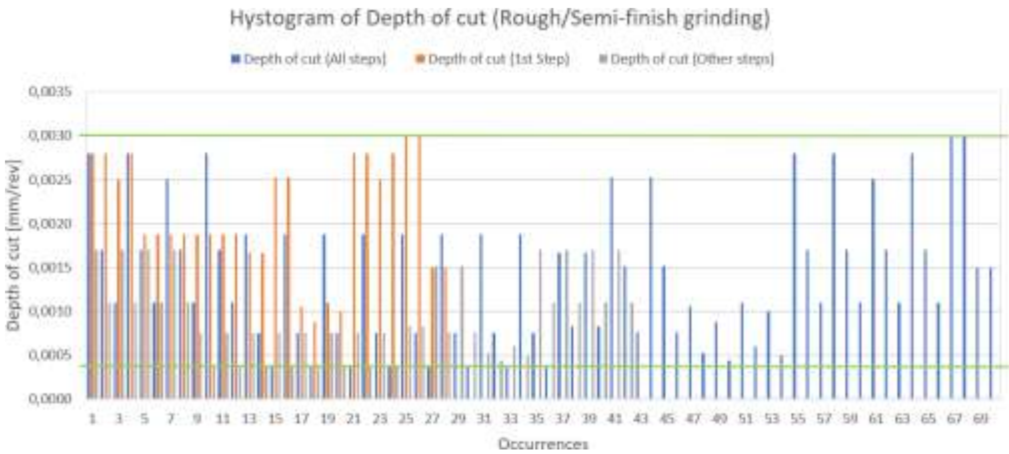

Fig.3Rough/semi-finishgrindingdepthofcut

Moreover, boxplots have been created to clearly highlight depth of cut range. In Fig.3 the blue boxplot represents the entire depthofcutrange.

The orange boxplot is referred to depth of cut used to perform machining step1. Grey boxplot shows depth of cut values used inothermachiningsteps(subsequenttomachiningstep 1).

Inputparametersoptimizertool

This tool using an Excel Solver optimizes a set of input parameters with the aim to maximize productivity within safe limits.Optimizer tool includes two different spreadsheets one for rough/semi-finish grinding and another for finish grinding. Here isreported the optimization model of machining input parameters for rough/semi-finish grinding, for finish grinding is similar butwithdifferentconstraintvalues

Variables:

Excel Solver spreadsheet provides results as shown in Fig. 4.Workpiece and wheel diameters, Mesh number, peripheral wheel andworkpiecespeed,feedrateandfeedcuttingangle(α) areintheinputblock.Peripheralworkpiecespeedandfeedrateareoptimizedrunning the solver in order to find the maximum output and so to identify the best parameter setting that ensures maximumproductivitywithinsafelimits(depthofcut, speed ratio, aggressivenessand chipthickness)

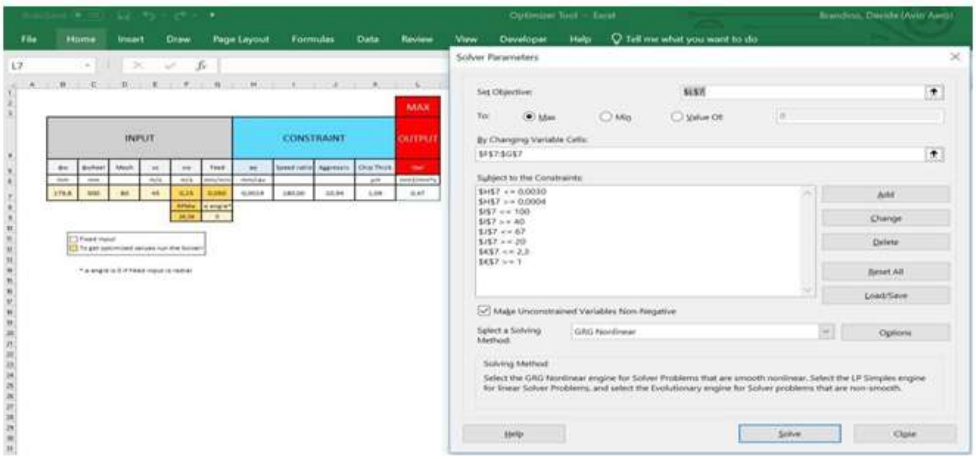

Fig.4Screenshotofoptimizerinterface

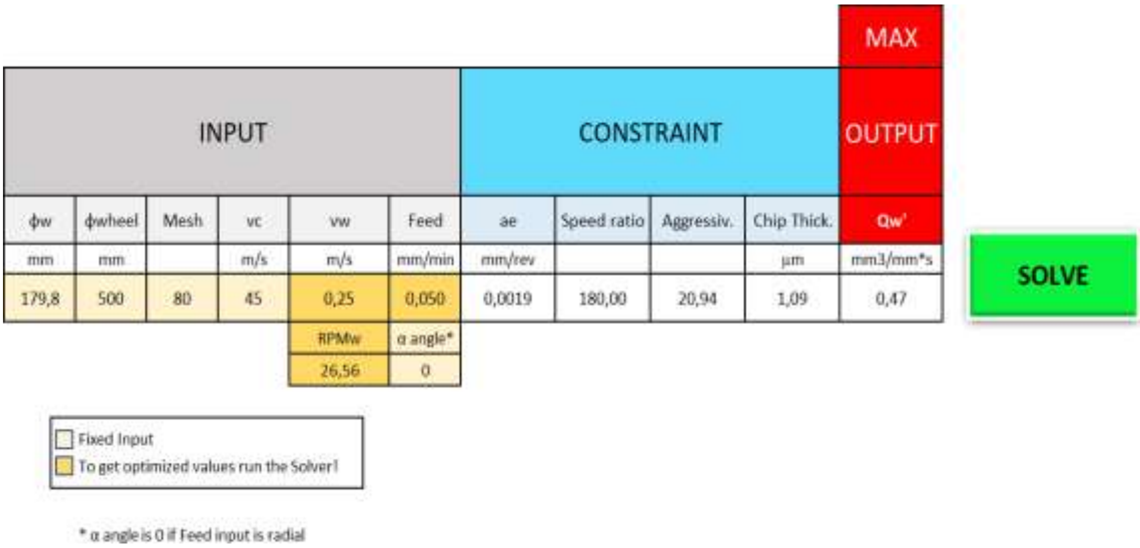

Fig.5Themacrobutton"Solve"

Anexcerptofcurrentrough grindingoperationsis showninTab.1,highlighted cellsinredarereferred tovaluesexceedinglimits.

INPUT								CONSTRAINT				TARGET
Feature N.	$Diameter_w$	$Diam_{wheel}$	Mesh	v_c	v_w	α	Feed	a_e	Speed Ratio	Aggressiv.	Chip Thickness	Current Qw'
	mm	mm		m/s	m/s		mm/min	mm/rev			µm	mm3/mm*s
1	271,8	500	80	45,00	0,24	45,00	0,048	0,0028	187,50	21,33	1,10	0,68
2	271,8	500	80	45,00	0,24	45,00	0,048	0,0028	187,50	21,33	1,10	0,68
3	179,8	500	80	45,00	0,25	45,00	0,050	0,0019	180,00	20,94	1,09	0,47
4	179,8	500	80	45,00	0,25	45,00	0,050	0,0019	180,00	20,94	1,09	0,47
5	179,8	500	80	45,00	0,25	45,00	0,050	0,0019	180,00	20,94	1,09	0,47
6	179,8	500	80	45,00	0,25	45,00	0,050	0,0019	180,00	20,94	1,09	0,47
7	116,9	600	60	27,17	0,44	45,00	0,120	0,0017	61,93	66,71	2,25	0,73
8	116,9	600	60	27,17	0,44	45,00	0,120	0,0017	61,93	66,71	2,25	0,73
9	271,8	500	80	45,00	0,24	45,00	0,048	0,0028	187,50	21,33	1,10	0,68
10	271,8	500	80	45,00	0,24	45,00	0,048	0,0028	187,50	21,33	1,10	0,68
11	271,8	750	54	27,49	0,24	45,00	0,051	0,0030	113,75	34,07	1,70	0,73
12	271,8	750	54	27,49	0,24	45,00	0,051	0,0030	113,75	34,07	1,70	0,73

Tab.1Excerptofcurrentroughgrindingprocess

Thesameviewwithoptimizedroughgrindingparameters(valuesinorange),obtainedfromoptimizedparameterstool,isi nTab.
2.Youcannoticeallcontrolparametersarewithinlimits andinthetargetcolumntheproductivityindicatorresultsincreasedatthemaximumvaluewithincontrolparametersconst raints.

Tab.2 Excerptofoptimized roughgrindingprocess

INPUT								CONSTRAINT				TARGET
Feature N.	$Diameter_w$	$Diam_{wheel}$	Mesh	v_c	v_w	α	Feed	a_e	Speed Ratio	Aggressiv.	Chip Thickness	New Qw'
	mm	mm		m/s	m/s		mm/min	mm/rev			µm	mm3/mm*s
1	271,8	500	80	45,00	0,73	45,00	0,154	0,0030	61,54	67,00	1,95	2,19
2	271,8	500	80	45,00	0,73	45,00	0,154	0,0030	61,54	67,00	1,95	2,19
3	179,8	500	80	45,00	0,63	45,00	0,202	0,0030	71,01	67,00	1,95	1,90
4	179,8	500	80	45,00	0,63	45,00	0,202	0,0030	71,01	67,00	1,95	1,90
5	179,8	500	80	45,00	0,63	45,00	0,202	0,0030	71,01	67,00	1,95	1,90
6	179,8	500	80	45,00	0,63	45,00	0,202	0,0030	71,01	67,00	1,95	1,90
7	116,9	600	60	27,17	0,33	45,00	0,161	0,0030	82,55	67,00	2,26	0,99
8	116,9	600	60	27,17	0,33	45,00	0,161	0,0030	82,55	67,00	2,26	0,99
9	271,8	500	80	45,00	0,73	45,00	0,154	0,0030	61,54	67,00	1,95	2,19
10	271,8	500	80	45,00	0,73	45,00	0,154	0,0030	61,54	67,00	1,95	2,19
11	271,8	750	54	27,49	0,44	45,00	0,094	0,0030	61,83	62,65	2,30	1,33
12	271,8	750	54	27,49	0,44	45,00	0,094	0,0030	61,83	62,65	2,30	1,33

Thesameviewwithoptimizedroughgrindingparameters(valuesinorange),obtainedfromoptimizedparameterstool,isinTab. 2.Youcannoticeallcontrolparametersarewithinlimits andinthetargetcolumntheproductivityindicatorresultsincreasedatthemaximumvaluewithincontrolparametersconstraints.

Anexcerptofcurrentsemi-finishgrindingoperationsisshowninTab.3,highlightedcellsinredarereferredtovaluesexceedinglimits.

Tab.3Excerptofcurrentsemi-finishgrindingprocess

INPUT								CONSTRAINT				TARGET
Feature N.	$Diameter_w$	$Diam_{wheel}$	Mesh	v_c	v_w	α	Feed	a_e	Speed Ratio	Aggressiv.	Chip Thickness	Actual Qw'
	mm	mm		m/s	m/s		mm/min	mm/rev			µm	mm3/mm*s
1	271,50	500	80	45,00	0,26	45,00	0,045	0,0025	173,08	21,41	1,10	0,64
2	271,50	500	80	45,00	0,26	45,00	0,045	0,0025	173,08	21,41	1,10	0,64
3	179,40	500	80	45,00	0,25	45,00	0,050	0,0019	180,00	20,96	1,09	0,47
4	179,40	500	80	45,00	0,25	45,00	0,050	0,0019	180,00	20,96	1,09	0,47
5	179,40	500	80	45,00	0,25	45,00	0,050	0,0019	180,00	20,96	1,09	0,47
6	179,40	500	80	45,00	0,25	45,00	0,050	0,0019	180,00	20,96	1,09	0,47
7	116,40	500	80	45,00	0,24	45,00	0,100	0,0025	187,50	27,68	1,26	0,61
8	116,40	500	80	45,00	0,24	45,00	0,100	0,0025	187,50	27,68	1,26	0,61
9	50,20	600	120	25,00	0,28	45,00	0,097	0,0011	88,19	50,00	1,38	0,25
10	39,63	600	120	25,00	0,28	0,00	0,096	0,0009	88,19	49,31	1,37	0,20
11	140,47	600	60	25,00	0,53	0,00	0,080	0,0011	46,85	66,47	2,25	0,59
12	68,48	600	60	25,00	0,37	0,00	0,103	0,0010	68,15	59,47	2,13	0,37
13	271,50	500	80	45,00	0,26	45,00	0,045	0,0025	175,86	21,41	1,10	0,64
14	271,50	500	80	45,00	0,26	45,00	0,045	0,0025	173,08	21,41	1,10	0,64
15	271,50	750	54	27,49	0,24	45,00	0,026	0,0015	113,94	24,09	1,43	0,36
16	271,50	750	54	27,49	0,24	45,00	0,026	0,0015	113,94	24,09	1,43	0,36

InTab.4 youcanseethesametable withadjustedinputparametersandtargetcolumnconfirmstheincreasedproductivity.

‘Tab.4Excerptofoptimized semi-finishgrindingprocess

INPUT								CONSTRAINT				TARGET
Feature N.	$Diameter_w$	$Diam_{wheel}$	Mesh	v_c	v_w	α	Feed	a_e	Speed Ratio	Aggressiv.	Chip Thickness	Actual Qw'
	mm	mm		m/s	m/s		mm/min	mm/rev			µm	mm3/mm*s
1	271,50	500,00	80,00	45,00	0,73	45,00	0,154	0,0030	61,56	67,00	1,95	2,19
2	271,50	500,00	80,00	45,00	0,73	45,00	0,154	0,0030	61,56	67,00	1,95	2,19
3	179,40	500,00	80,00	45,00	0,63	45,00	0,202	0,0030	71,06	67,00	1,95	1,90
4	179,40	500,00	80,00	45,00	0,63	45,00	0,202	0,0030	71,06	67,00	1,95	1,90
5	179,40	500,00	80,00	45,00	0,63	45,00	0,202	0,0030	71,06	67,00	1,95	1,90
6	179,40	500,00	80,00	45,00	0,63	45,00	0,202	0,0030	71,06	67,00	1,95	1,90
7	116,40	500,00	80,00	45,00	0,54	45,00	0,264	0,0030	84,03	67,00	1,95	1,61
8	116,40	500,00	80,00	45,00	0,54	45,00	0,264	0,0030	84,03	67,00	1,95	1,61
9	50,20	600,00	120,00	25,00	0,25	45,00	0,198	0,0021	100,00	67,00	1,60	0,52
10	39,63	600,00	120,00	25,00	0,25	0,00	0,202	0,0017	100,00	67,00	1,60	0,42
11	140,47	600,00	60,00	25,00	0,33	0,00	0,133	0,0030	76,54	67,00	2,26	0,98
12	68,48	600,00	60,00	25,00	0,25	0,00	0,193	0,0028	100,00	67,00	2,26	0,69
13	271,50	500,00	80,00	45,00	0,73	45,00	0,154	0,0030	61,56	67,00	1,95	2,19
14	271,50	500,00	80,00	45,00	0,73	45,00	0,154	0,0030	61,56	67,00	1,95	2,19
15	271,50	750,00	54,00	27,49	0,44	45,00	0,094	0,0030	61,85	62,65	2,30	1,33
16	271,50	750,00	54,00	27,49	0,44	45,00	0,094	0,0030	61,85	62,65	2,30	1,33

Theresultantmachiningtimereductionisabout70%withrespectthecurrent,asdetailedinTab.5

Tab.5MachiningTimecalculation

	CurrentMachiningTime	NewMachiningTime
	min	min
Roughgrinding	1937.73	700.98
Semi-finishgrinding	2682.03	784.21
Total	4619.76	1485.19
MachiningTimeReduction[%]	67.85%	

V. CONCLUSION

Grinding standard allows to identify stable set of parameters and therefore a more robust process mainly to avoid grinding abusesdifficulttobe detectedthatcouldcausefailuresduringflight.

1. Aspertheresultsoftheoptimizedparametero btained fromVBAexcelsolver toolthenewmachiningtimehasbeenreducedby63.82 %, for rough grinding from current machining time1937.73 minutes to new machining time 700.98 minutes. and for semi-finishgrinding fromcurrentmachiningtime2682.03minutesto newmachiningtime784.21minutes.
2. Aspertheresultsoftheoptimizedparametero btainedfromVBAexcelsolvertoolthenewmachiningti mehasbeenreducedby70.76%, for semi-finish grinding from current machining time 1937.73 minutes to new machining time 700.98 minutes and hence,theoverall reductioninmachiningtime is67.85%.
3. The target has achieved by the definition of a standard set of process optimized parameters that creates a surface consistent toaccuracy,integrityand damage tolerancerequirementsand byarobustcontrolofthese parameters.

Continuous improvement shall be pursued on process control methods to identify the optimal parameter settings and to furtherpreventgrindingabuses.Processmonitoring(e. g.,grindingpowermonitoring)couldbehelpfulforthisp urpose,thustheideaofitsinstallationonCNCgrinders.

Futurework

1. Theageofthegrindingwheelplaysasignificantrol eingrindingburn.Thedressingparameters,suchas dressingangleanddressinglead,influencethelifeo fthewheel.Adesignofexperimentscanbeperform edtoinvestigatetheimpactoftheseparameters.
2. Materialandsurfacehardeningcanbothhaveanim pactontheonsetofgrindingburn.Taguchi'smetho

dtestscanbeusedtoinvestigatethe effectsofthesenoise variables.

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