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PARAMETERIC STUDY OF FACE AND SHOULDER 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 wheel rotational speed are among the process characteristics that affect the cylindrical grinding operation. Because increasing both peripheral workpiece speed and work-piece feed has a negative influence on surface roughness, while high material removal causes a reduction in surface roughness, hence, peripheral workpiece speed and work-piece feed are considered as crucial parameters. One of the most popular machining methods used in finishing operations is cylindrical grinding process. In terms of quantity and quality, the metal removal rate and surface finish are the most critical output responses in the manufacturing process.

The fundamental goal of this research is to investigate the critical process variables that induce grinding burn and influence the quality of face and sholuder cylindrical grinding. This research identifies the major grinding factors, which are subsequently investigated 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' (material removal rate) was used as a target.

The overall machining time has been reduced by 67.85 percent as a result of the optimised parameters obtained from the VBA excel solver tool. The target has achieved by the definition of a standard set of process optimized parameters that creates a surface consistent to accuracy, integrity and damage tolerance requirements and by a robust control of these parameters.

1. INTRODUCTION

Grinding is an important technology in the metal manufacturing process because it ensures the needed surface finish when other manufacturing processes fail to satisfy product specifications. Grinding is used in the last phases of the product manufacturing cycle, when the machined part's value is already high and errors can be costly. Grinding affects physical layer qualities such as residual stress, 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 have great financial performance in today's global manufacturer competition, thanks to their high quality reputation.

However they must constantly improve their performances first of all in terms of quality and delivering time to maintain leadership in their business. This becomes possible only innovating, inventing, investing in Research and Development and last but not least investing in people knowledge.

The first was a thorough examination of the grinding process, as well as knowledge of aeronautical products, particularly gears; the second was a meticulous data collection of the current grinding process from the Industries; the third was a thorough analysis of the gathered data; and the fourth was a multi-pronged approach to improve the current process, taking into account not only the grinding but also the needs of the technologists, assisting them in the definition of grinding parameters.

Grinding Process

Abrasives have been used for shaping for over 2000 years. Sharpening early knives, tools, and weapons was done with abrasive stones. Abrasives have been used since ancient times to cut and shape rocks and stones for the construction of buildings and edifices such as the pyramids. Abrasives were also used to cut and polish gemstones. Abrasives are still used in a wide range of applications today, and the abrasives industry is responsible for the production of many modern mechanical parts. Even in the beginning, grinding was a finishing process used on products nearing the most valuable stage of production.

Grinding was invented as a metal manufacturing process in the nineteenth century, and it was crucial in the development of tools, as well as the production of IC engines, gearboxes, transmission systems, and eventually jet engines, astronomical instruments, and other electronics components.

In modern production, the phrase "grinding" refers to machining with high-speed abrasive wheels, pads, and belts. Grinding wheels are available in a wide range of shapes, sizes, and abrasive kinds.

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 the required quality. In the latter half of the twentieth century, this resulted in fast development. A tendency toward hard ceramic materials has emerged in modern technology, posing new manufacturing constraints.

2. Literature Review

The literature review focuses on research that has been published in linked journals and articles. The literature discusses the effects of input and machining parameters on output response parameters using optimization techniques for the cylindrical grinding process.

L. P. George et al. [1] "Experiments using a cylindrical grinding machine were carried out in order to better understand the cutting mechanisms. To investigate the impact of cutting speed, depth of cut, and material hardness on surface roughness while keeping all other variables constant. To establish an empirical relationship between the obtained surface roughness value and process parameters Experiments were carried out on a MILANO RICEN RUM 1 cylindrical grinding machine equipped with a L9 orthogonal array.

D. Pal et al. [2] "Surface roughness was investigated experimentally using cylindrical grinding process parameters. The tests were carried out on a universal tool and cutter grinding machine equipped with a L9 orthogonal array. Material hardness, work piece speed, and grinding wheel grains are all input machining variables. Die steel (EN24, EN31) was employed as the work component for this experiment. The Taguchi method was utilised to optimise the parameters of the process. The optimal value of surface roughness for the cylindrical grinding process is found to be 1.07 Ra. When the speed is increased from 100 to 160 rpm, the surface roughness diminishes. Surface roughness decreases when grinding wheel grains are adjusted from G 46 to G 60."

K. Mekala et al. [3] "Proposed cylindrical grinding machine experiments on austenite stainless steel rod (AISI 316). Cutting speed, depth of cut, and feed rate are all input variables. The L9 orthogonal array was utilised in a Taguchi design of experiment. ANOVA and the S/N ratio are used to optimise the experiment. Metal removal rate and surface roughness are the output parameters. The work piece was made using AISI 316 round rods with a diameter of 50 mm and a length of 70 mm. Cutting at a speed of 560 m/min, with a depth of cut of 0.05mm and a feed of 0.130mm, metal was removed. Cutting speed is shown to be the most important factor, whereas depth of cut is better for grinding results.."

M. Melwin et al. [4] "Using a cylindrical grinding machine, performed experiments on OHNS steel (AISI 0-1) rounds. The surface quality of OHNS steel will be investigated in three levels using a L9 orthogonal array. The input parameters are work speed, depth of cut, and number of passes, while the response parameter is material removal rate. The work material was OHNS steel round bars with a diameter of 25 mm and a length of 70 mm. During the trial, the best parameters for metal removal rate of OHNS steel cylindrical rounds were 0.02mm depth of cut, 150 rpm work speed, and 1 pass."

N. Kumar et al. [5] "Using the Taguchi technique, the influence of optimised machine parameters on surface roughness in cylindrical grinding 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 surface roughness. Grinding speed 210rpm, depth of cut 0.04mm, and feed 0.11mm/rev were used to produce experimental findings for minimal surface roughness. The obtained optimal minimum surface roughness is 0.238m."

3. METHODOLOGY

1. Study identifies the essential grinding factors, which are then optimized using VBA Excel tool for zero scrap during the CNC cylindrical grinding process.

2. The idea is to use the optimal parameters obtained from the VBA Excel tool to discover the underlying cause of grinding burn using two variables Peripheral workpiece speed and feed rate and others are best parameter setting that ensures maximum productivity within safe limits (depth of cut, speed ratio, aggressiveness and chip thickness).

4. RESULTS AND DISCUSSION

Current process input parameters have been plotted in some graphs.

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, therefore grinding operations are basically classified in two classes of range parameters.

A machining operation is the elapsed time during which the grinding wheel removes a certain material overstock, obtaining final phase part diameter ± tolerances as required by operation sheet according to 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 in next machining steps (classified as "other machining steps", used to get better surface finish).

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

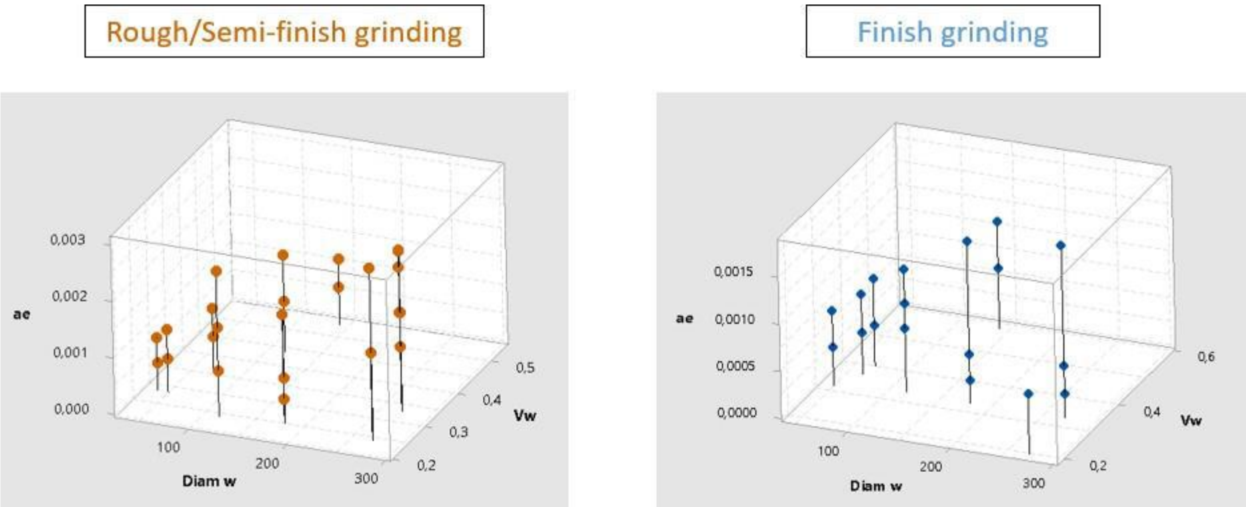

Fig. 1 3D plot of depth of cut (mm/rev)

Moreover, an interpolation of these data thru a 3D surface plot (Fig. 1) has been used to give an easier interpretation of the Z values that is more or less flat.

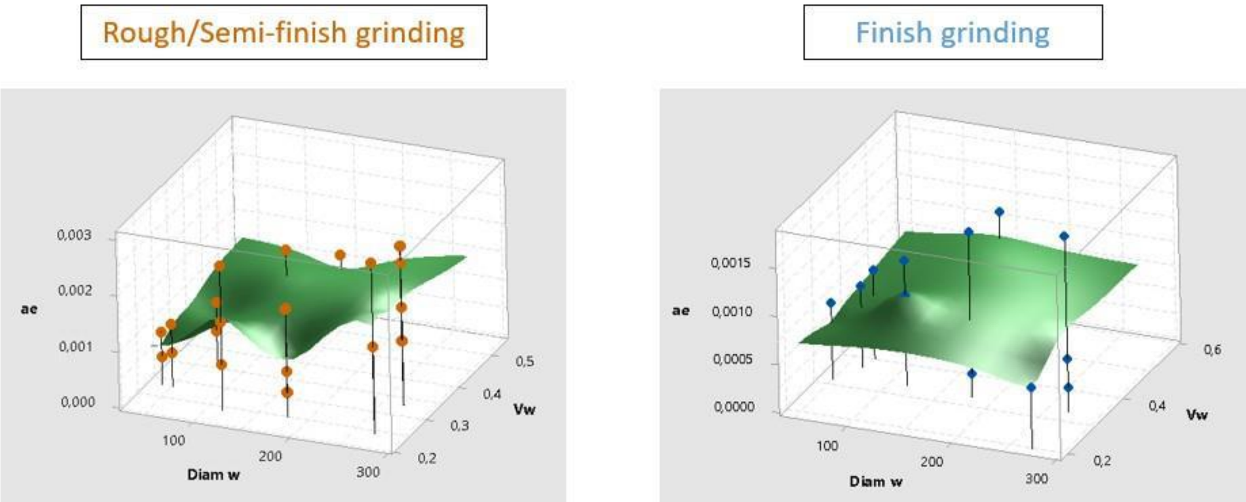

Fig. 2 3D surface plot of depth of cut (mm/rev)

Results confirm that feed rate is different with respect different diameter workpieces, but the depth of cut is more or less constant considering also machining steps. The current safety range for depth of cut to be applied on rough/semi-finish grinding is shown in Fig.2.

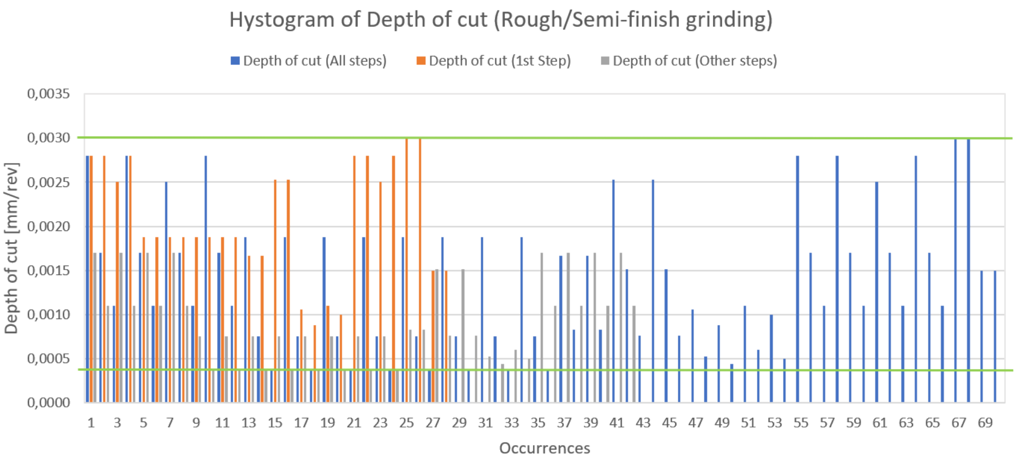

Fig. 3 Rough/semi-finish grinding depth of cut

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

The orange boxplot is referred to depth of cut used to perform machining step1. Grey boxplot shows depth of cut values used in other machining steps (subsequent to machining step1).

Input parameters optimizer tool

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 is reported the optimization model of machining input parameters for rough/semi-finish grinding, for finish grinding is similar but with different constraint values

Variables:

Excel Solver spreadsheet provides results as shown in Fig. 4.Workpiece and wheel diameters, Mesh number, peripheral wheel and workpiece speed, feed rate and feed cutting angle (α) are in the input block. Peripheral workpiece speed and feed rate are optimized running the solver in order to find the maximum output and so to identify the best parameter setting that ensures maximum productivity within safe limits (depth of cut, speed ratio, aggressiveness and chip thickness).

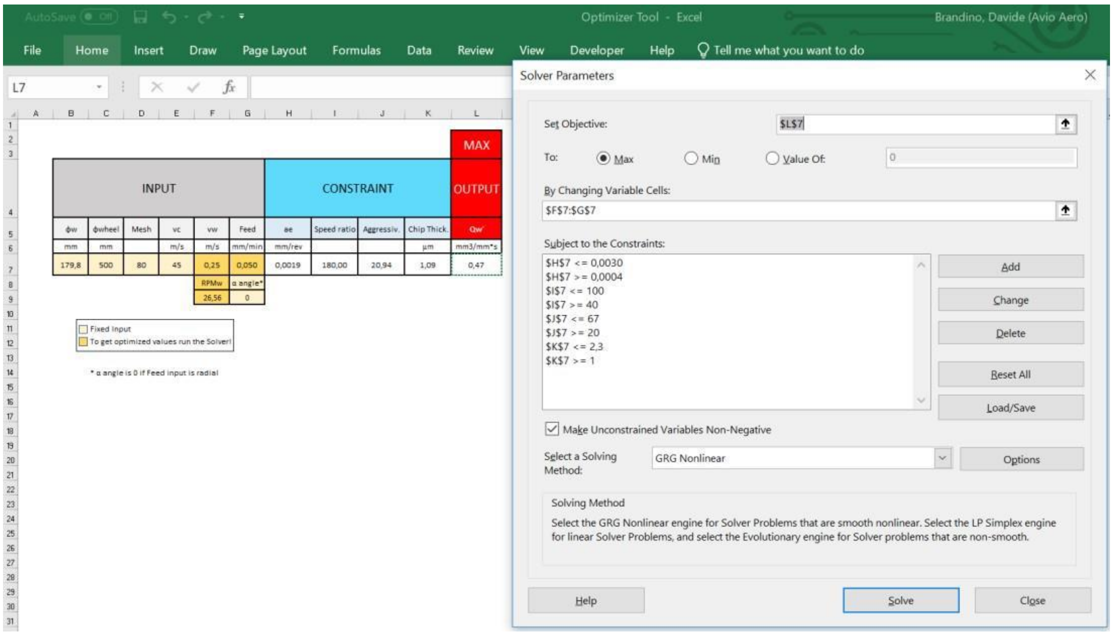

Fig. 4 Screenshot of optimizer interface

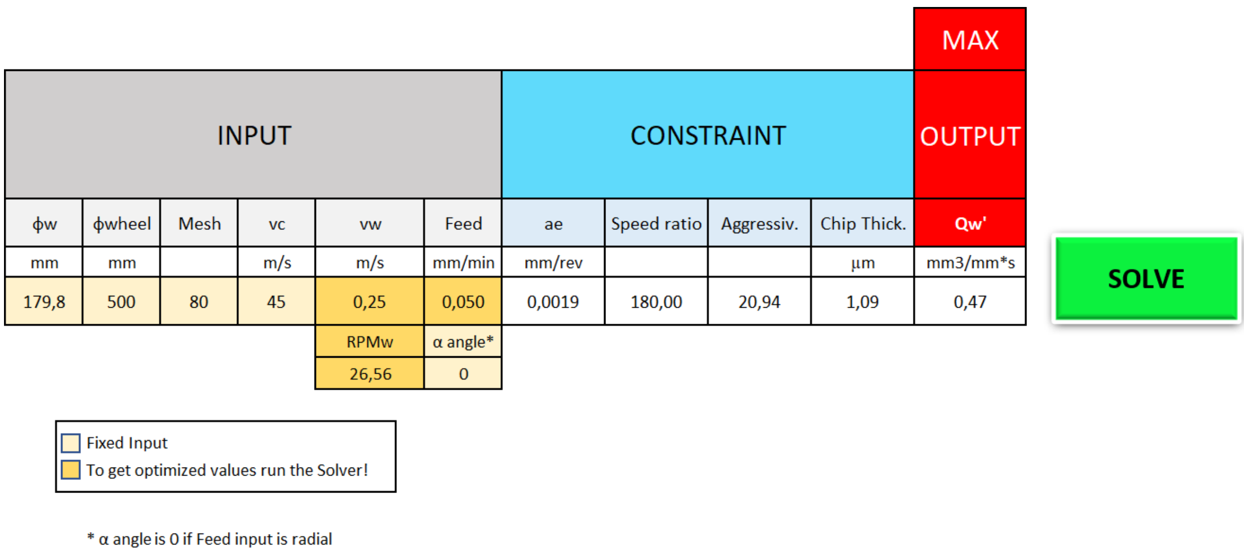

Fig. 5 The macro button "Solve"

An excerpt of current rough grinding operations is shown in Tab. 1, highlighted cells in red are referred to values exceeding limits.

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.1 Excerpt of current rough grinding process

The same view with optimized rough grinding parameters (values in orange), obtained from optimized parameters tool, is in Tab. 2. You can notice all control parameters are within limits and in the target column the productivity indicator results increased at the maximum value within control parameters constraints.

Tab. 2 Excerpt of optimized rough grinding process

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

The same view with optimized rough grinding parameters (values in orange), obtained from optimized parameters tool, is in Tab. 2. You can notice all control parameters are within limits and in the target column the productivity indicator results increased at the maximum value within control parameters constraints.

An excerpt of current semi-finish grinding operations is shown in Tab. 3, highlighted cells in red are referred to values exceeding limits.

Tab. 3 Excerpt of current semi-finish grinding process

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

In Tab. 4 you can see the same table with adjusted input parameters and target column confirms the increased productivity.

Tab. 4 Excerpt of optimized semi-finish grinding process

The resultant machining time reduction is about 70 % with respect the current, as detailed in Tab. 5

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

Tab. 5 Machining Time calculation

	Current Machining Time	New Machining Time
	min	min
Rough grinding	1937.73	700.98
Semi-finish grinding	2682.03	784.21
Total	4619.76	1485.19
Machining Time Reduction [%]	67.85 %	

5. CONCLUSION

Grinding standard allows to identify stable set of parameters and therefore a more robust process mainly to avoid grinding abuses difficult to be detected that could cause failures during flight.

1. As per the results of the optimized parameter obtained from VBA excel solver tool the new machining time has been reduced by 63.82%, for rough grinding from current machining time1937.73 minutes to new machining time 700.98 minutes. and for semi-finish grinding from current machining time 2682.03 minutes to new machining time 784.21 minutes.

2. As per the results of the optimized parameter obtained from VBA excel solver tool the new machining time has been reduced by 70.76%, for semi-finish grinding from current machining time 1937.73 minutes to new machining time 700.98 minutes and hence, the overall reduction in machining time is 67.85%.

3. The target has achieved by the definition of a standard set of process optimized parameters that creates a surface consistent to accuracy, integrity and damage tolerance requirements and by a robust control of these parameters.

Continuous improvement shall be pursued on process control methods to identify the optimal parameter settings and to further prevent grinding abuses. Process monitoring (e.g., grinding power monitoring) could be helpful for this purpose, thus the idea of its installation on CNC grinders.

Future work

1. The age of the grinding wheel plays a significant role in grinding burn. The dressing parameters, such as dressing angle and dressing lead, influence the life of the wheel. A design of experiments can be performed to investigate the impact of these parameters.

2. Material and surface hardening can both have an impact on the onset of grinding burn. Taguchi's method tests can be used to investigate the effects of these noise variables.

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