Machine Cutter using DOE

This project centers around the optimization study of a Cutting Machine, aiming to identify the most effective combination of parameters for optimal performance, with the primary objective being the enhancement of duration (measured in the number of cycles). A higher cycle count is deemed more favorable for increased productivity. Notably, the cycles typically operate at a relatively low frequency, around 6-7 cycles per second. The emphasis extends beyond mere productivity improvement, encompassing a commitment to sustainability in the pursuit of operational enhancements.

Experimental Parameters and Levels:

The available experimental parameters and their respective levels for optimization are as follows:

Sharp Teeth:
Low Level: 8 (discrete)
High Level: 10 (discrete)

Speed (rpm):
Low Level: 4320 (continuous)
High Level: 5650 (continuous)

Cutter Diameter (mm):
Low Level: 125 (continuous)
High Level: 200 (continuous)

These parameters were carefully selected to explore the impact of variations in sharp teeth, speed, and cutter diameter on the optimization study.

DOE

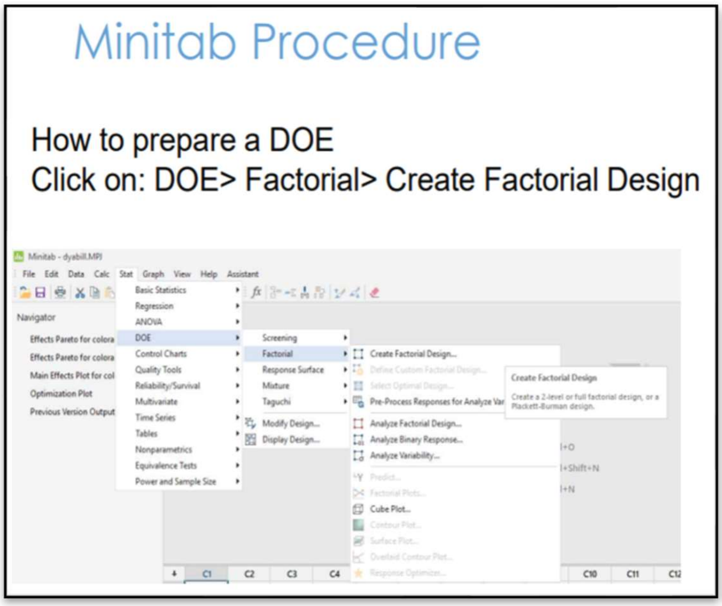
DOE is a test or series of tests that enable us to compare two or more methods to determine which is better, or determine levels of controllable factors to optimize the yield of a process or minimize the variability of the output In particular DOE help us to improve the processes by:

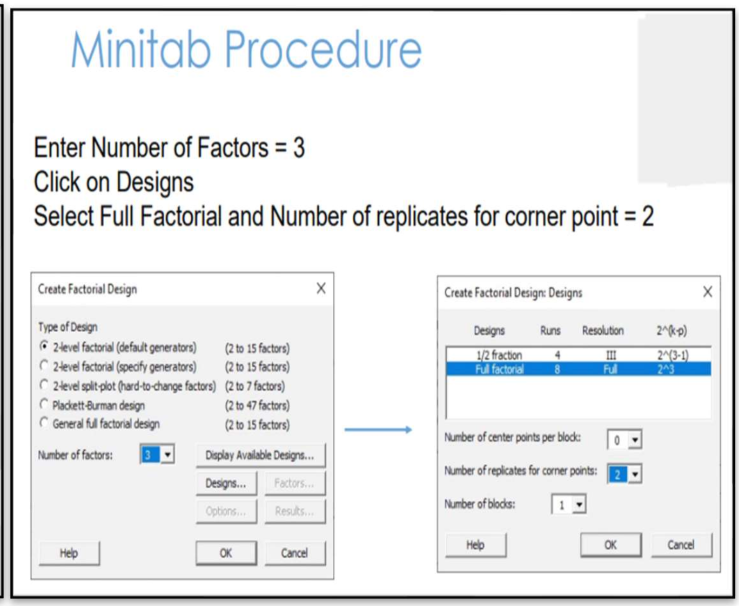
1. Screening the factors to determine which are important to explain process variations and to try to understand how factors interact and drive the process (Characterization or Screening Experiments)
2. Finding the factor settings that produce optimal process performance (Optimization Experiments)

Methodology

Initial Step: Design of Experiment (DOE) in MiniTab

To commence, I initiate the Design of Experiment (DOE) process in MiniTab to find all the possible combination. The outlined procedure is depicted in the accompanying image below:





The picture on the right represents the result provided by the MiniTab with all the combinations of the factors and their respective number of cycles.

C5	C6	C7	C8
n of teeth	rpm	cutter diameter	n of cycle
8	4320	125	5180
10	4320	125	6828
8	5650	125	2140
10	5650	125	6535
8	4320	200	5523
10	4320	200	7548
8	5650	200	6328
10	5650	200	10450
8	4320	125	5463
10	4320	125	6125
8	5650	125	1882
10	5650	125	5987
8	4320	200	5966
10	4320	200	7128
8	5650	200	6102
10	5650	200	10684

Factorial Design

Following the initiation of the Design of Experiment, a thorough analysis of the factors was conducted. The presented image illustrates that the Adjusted R-squared (R-Sq(Adj)) attains an exceptionally high value of 98.31%. This significant value serves as compelling evidence that these factors wield substantial influence, making them optimal for the model.

Model Summary

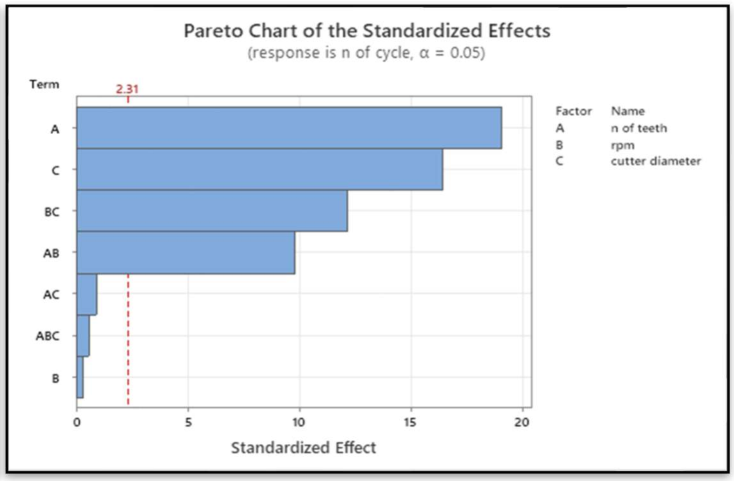
S	R-sq	R-sq(adj)	R-sq(pred)
297.872	99.10%	98.31%	96.39%

The image below presents a comprehensive summary of the analysis, indicating the overall significance of the model with a p-value of 0.000, which is less than the threshold of 0.005. The Pareto graph on the right further affirms the significance of specific factors, each having a p-value less than 0.005. Noteworthy factors include:

1. Sharp teeth
2. Cutter diameter
3. Interaction of sharp teeth and speed
4. Interaction of speed and cutter diameter

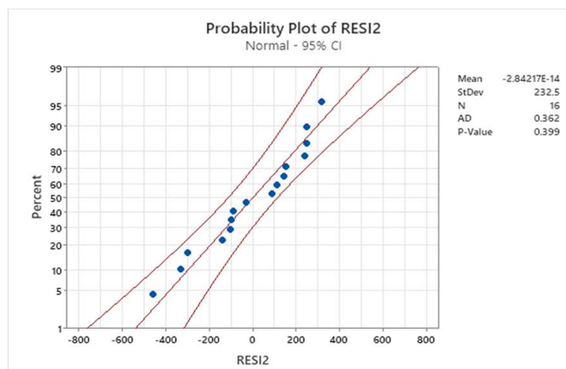
Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	7	77918217	11131174	125.45	0.000
Linear	3	56199046	18733015	211.13	0.000
n of teeth	1	32208463	32208463	363.00	0.000
rpm	1	7526	7526	0.08	0.778
cutter diameter	1	23983058	23983058	270.30	0.000
2-Way Interactions	3	21690863	7230288	81.49	0.000
n of teeth*rpm	1	8565866	8565866	96.54	0.000
n of teeth*cutter diameter	1	73035	73035	0.82	0.391
rpm*cutter diameter	1	13051963	13051963	147.10	0.000
3-Way Interactions	1	28308	28308	0.32	0.588
n of teeth*rpm*cutter diameter	1	28308	28308	0.32	0.588
Error	8	709823	88728		
Total	15	78628040			



Subsequent Analysis with Selected Significant Factors:

With the insight gained from the preceding graph, the analysis will now be reiterated, focusing specifically on the selected significant factors. This refined approach aims to delve deeper into the impact of these factors on the model's outcomes.

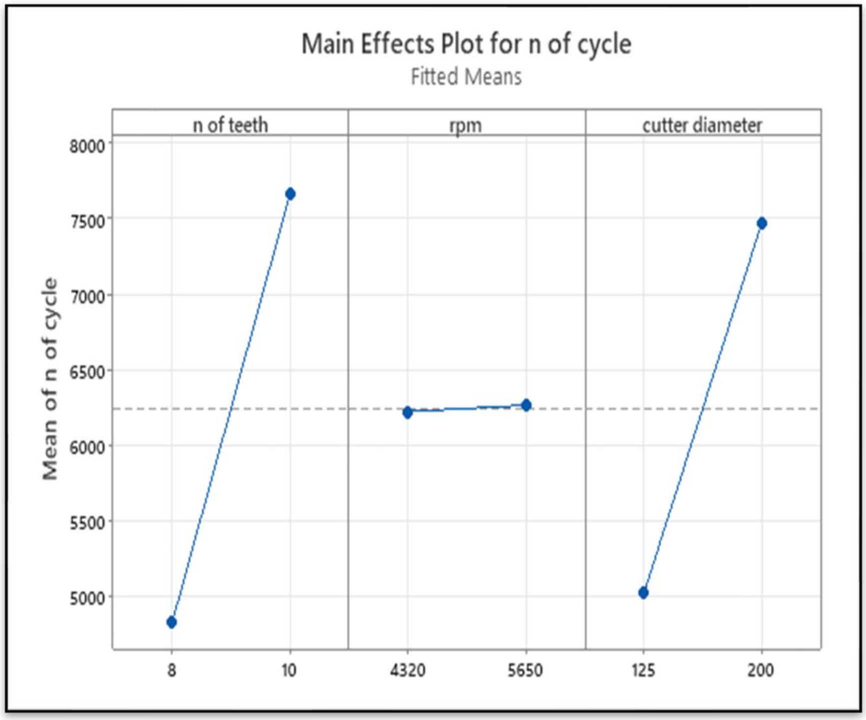


Upon the repetition of the procedure, the examination of residuals normality reveals a p-value of 0.399, surpassing the significance threshold of 0.005. This result substantiates the acceptance of the null hypothesis, affirming that the residuals are normally distributed.

Factorial Plots

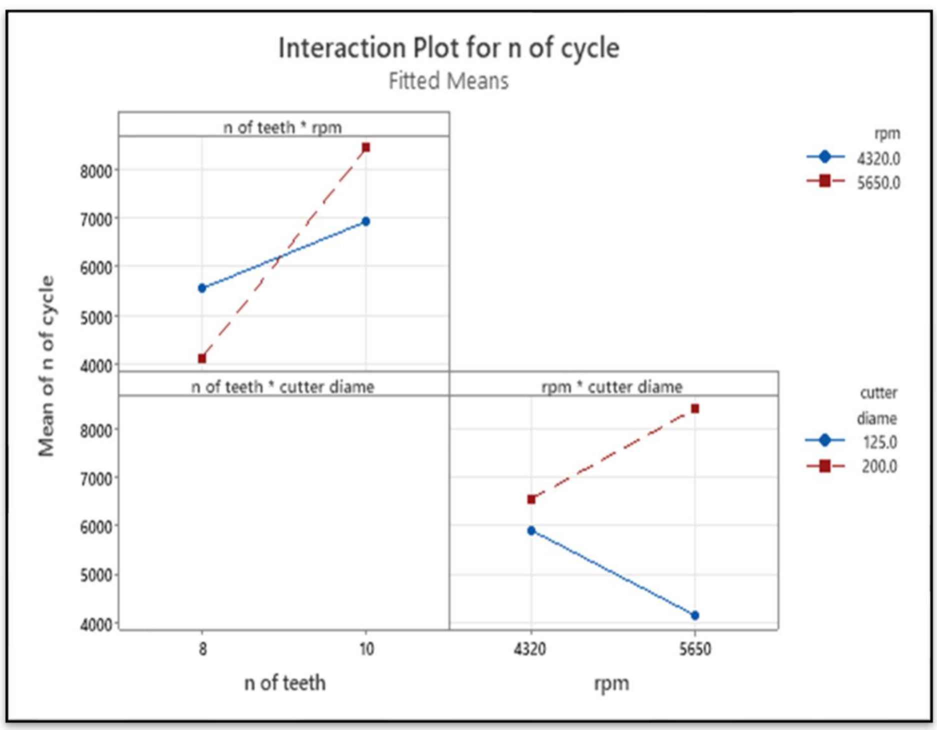
Its time to analyze the affect of different factors on the number of cycle, for this MiniTab Factorial Plot.

Linear Contribution Analysis:



The presented graph illustrates the linear contribution of each factor to the mean of the number of cycles. Notably, the speed of the cutter (rpm) exhibits a zero effect on the number of cycles, indicating that either speed (4320 or 5650) can be chosen interchangeably. On the other hand, both the number of teeth and cutter diameter showcase a positive slope, suggesting an incremental impact on the number of cycles. Consequently, opting for 10 teeth and a 200 mm cutter diameter is deemed more favorable, aligning with the objective of maximizing the number of cycles.

Interaction Results Analysis:



The image on the right illustrates diverse outcomes resulting from the interaction between factors. Specifically:

The interaction between the number of teeth and rpm suggests that, for achieving the maximum mean of the number of cycles, the optimal rpm should be 5650 when combined with 10 teeth.

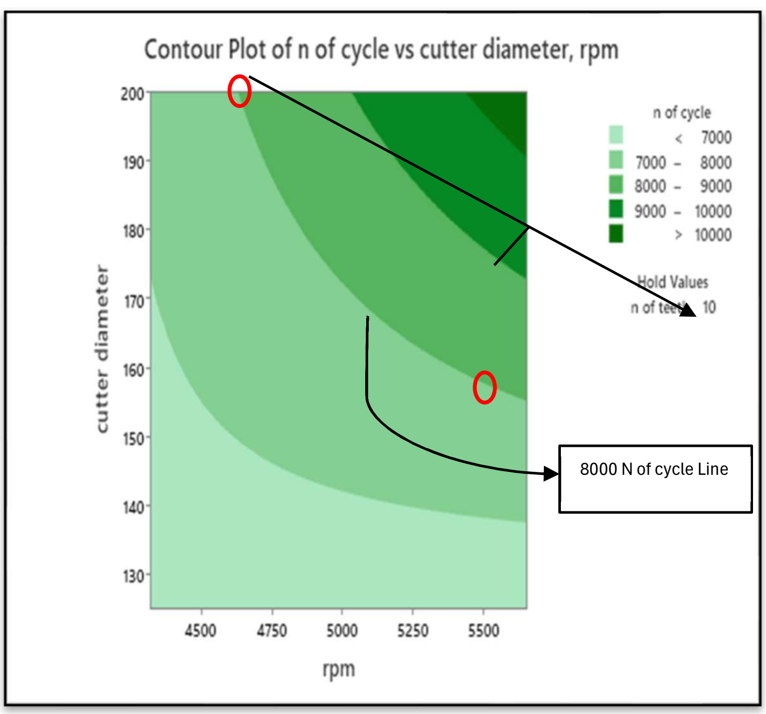
Meanwhile, the interaction between rpm and cutter diameter indicates that a cutter diameter of 200 mm, coupled with 5650 rpm, leads to an improved number of cycles.

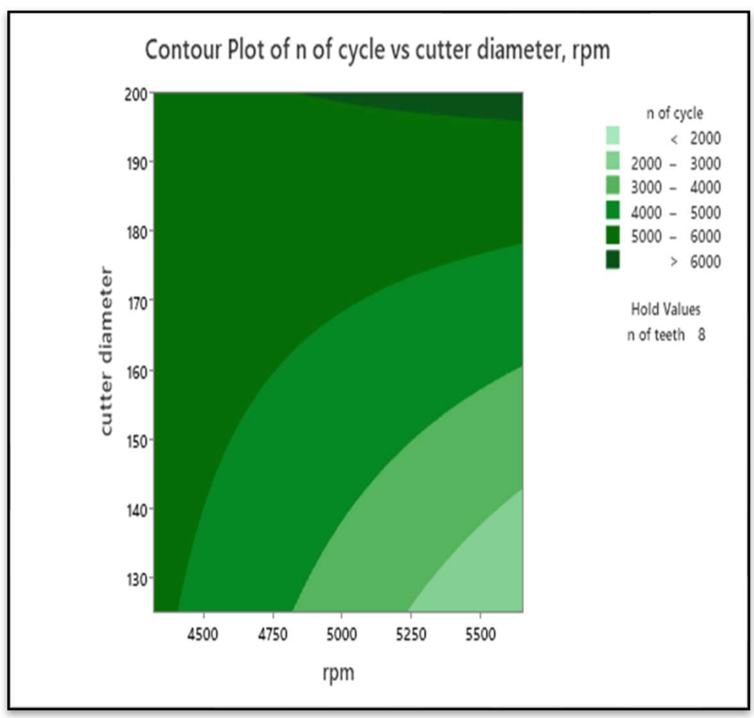
The above findings align seamlessly with the earlier Linear Contribution Analysis. These consistent insights provide valuable guidance for configuring the factors, reinforcing the optimization objective of maximizing the number of cycles. The convergence of results enhances the robustness of the conclusions drawn from the analysis.

Contour Plot

The left plot showcases the change in the number of cycles when the number of teeth is fixed at 10, resulting in a notable increase beyond 10,000 cycles depending upon the cutter diameter. Conversely, the right plot demonstrates that when the number of teeth is fixed at 8, based on the cutter diameter the number of cycles can reach a maximum of 6,000. These detailed examinations provide a comprehensive understanding of how variations in factors influence the desired outcome of maximizing the number of cycles. This more intricate analysis empowers decision-making by providing the flexibility to choose between the number of cycles based on specific needs and preferences. The detailed insights garnered enable the identification of an optimal combination that aligns precisely with desired outcomes.

The pivotal insight derived from the graph is the constancy in the number of cycles along the curve line. This implies that alterations in the cutter diameter and rpm can be made while still achieving the same desired outcome. For instance, if the target number of cycles is 8000, this can be achieved either by employing a cutter diameter of 200 while maintaining rpm at 4750 or by utilizing a cutter diameter of approximately 160 and increasing rpm to 5500. This flexibility in design allows for strategic adjustments based on factors such as design constraints, rpm limitations, or cost considerations, while still attaining the specified outcome.





Response Optimizer

MiniTab Simulator for Factor Combinations:

The image from MiniTab software serves as a simulator, offering a dynamic platform where lines can be manipulated to explore and find the desired results. This interactive tool provides related combinations of factors, granting a high degree of flexibility in the analysis. It essentially represents a variation of the same analysis, albeit with a different approach, enhancing the adaptability and ease of exploring diverse factor combinations to achieve specific outcomes.