CASE STUDY: EXPERIMENTAL STUDY OF DIFFERENT TAP FINISHES

Objective

- To assess and compare the effects of different polishes, grinds, cutting fluids and speeds on the forces, namely torque and thrust, for the internal thread forming process.

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Design of Experiments

- The four variables considered in the experiments and their different levels are as shown in Table 1.

Table1 Levels Of Different Variables

Variable Number	*Variable Name*	*Low Level (-1)*	*High Level (+1)*
1	Grind (X_1)	A	D
2	Finish (X_2)	Unpolished	Brush-polished
3	Speed (X_3)	50 (sfm)	100 (sfm)
4	Cutting fluid (X_4)	Emulsion	Oil

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Design of Experiments

- Experiments in ***Table 1*** were done at all the different combinations of the above variable levels with 3 repetitions and 2 replications of each unique combination.
- The repetition experiments were all done consecutively without changing the setup.

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Design of experiments

- The replicates, on the other hand, were included in a randomized testing sequence and were carried out to obtain an error estimate that would later on be used in statistical analysis of the results.

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Experimental Setup

- The experiments were done using Mori-Seiki TV-30 vertical milling, drilling and tapping machine.
- The workpiece material used was 4340 steel and M6X1 form taps with different grinds and polishes were used.

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Experimental Setup

- The holes for tapping were drilled to 13/64" and then reamed to 7/32" to obtain 65% threads.
- Either oil (Trim Taplight) or emulsion (Microsol 265 10:1 ratio with water) was used as the cutting fluid.
- The spindle speeds used were such as to provide surface speeds of 50 and 100 sfm.

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Response Parameters

- The force signals experienced during the above experiments were collected using Kistler 4 – component dynamometer (Model No. 9272).
- The thrusts and torques so obtained were averaged over ten teeth (from teeth 50 to teeth 59) to obtain the response parameters to be used in the analysis (refer to ***Figure 1***).

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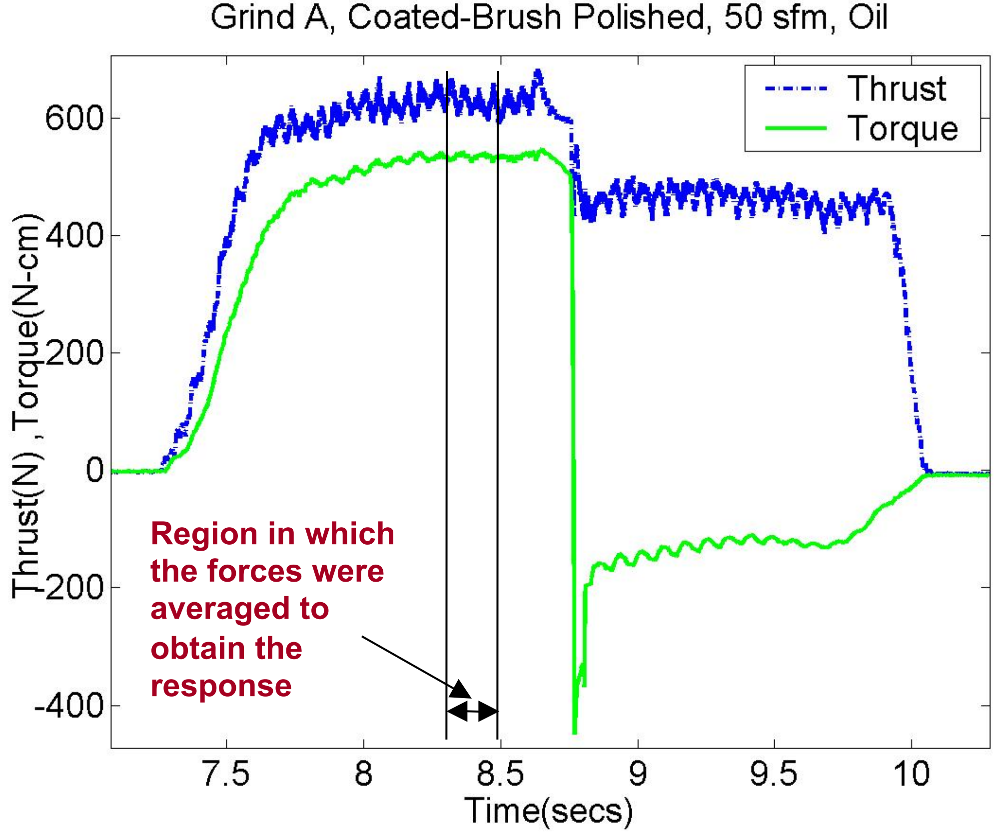
Figure 1 Response Parameter Identification



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Response Parameters

- Teeth 50 to 59 (Shown in Fig.2)were chosen since they are the last few teeth on the back taper of the tap and the effects of elastic recovery on these teeth would be minimal.

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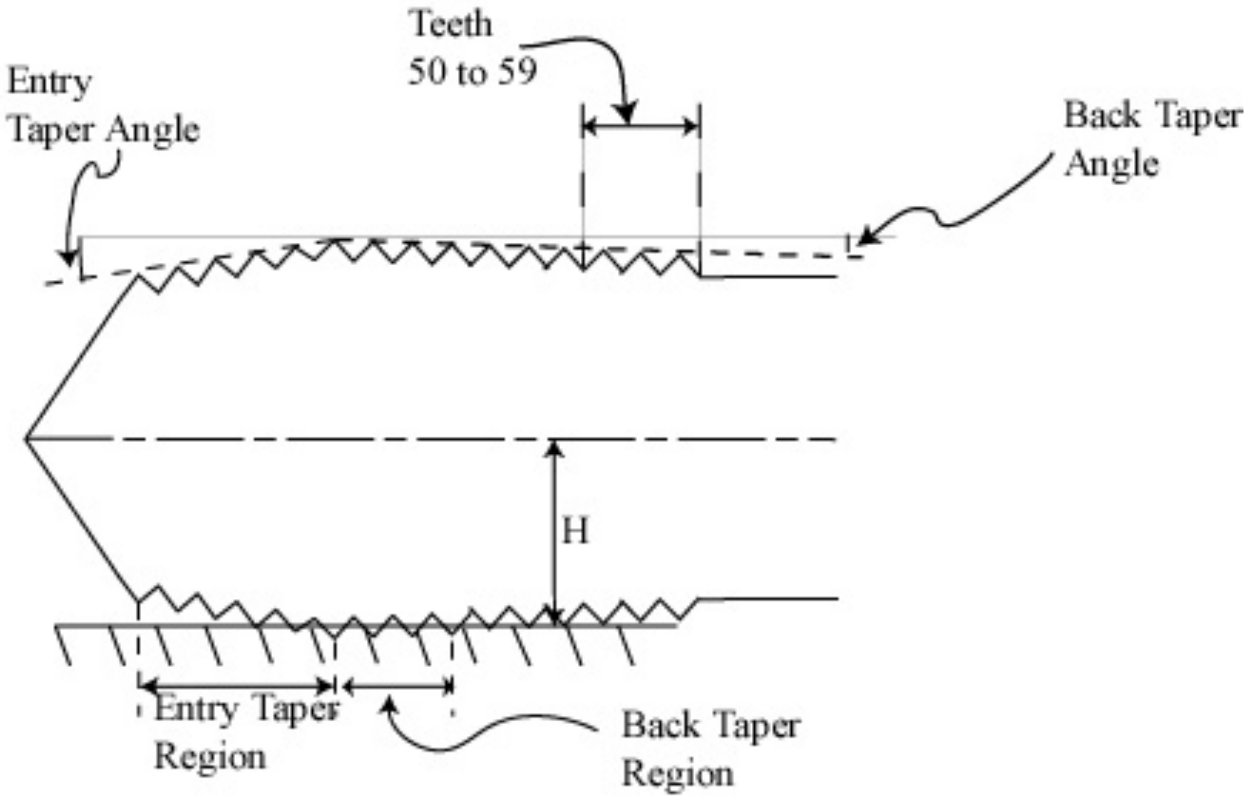
Fig.2 Tap Geometry



SAMPLE CALCULATION FOR EFFECT ANALYSIS AND STATISTICAL TESTS

Table 2 Design Matrix

Test	Grind (x_1)	Finish (x_2)	Speed (x_3)	Cutting fluid (x_4)	Torque Replicate 1 (y_{i1})	Torque Replicate 2 (y_{i2})
1	-1	-1	-1	-1	450.74	474.50
2	+1	-1	-1	-1	447.63	468.51
3	-1	+1	-1	-1	562.47	557.21
4	+1	+1	-1	-1	568.25	593.79
5	-1	-1	+1	-1	552.96	538.99
6	+1	-1	+1	-1	554.51	547.38
7	-1	+1	+1	-1	543.96	538.58
8	+1	+1	+1	-1	545.22	535.22
9	-1	-1	-1	+1	719.51	765.87
10	+1	-1	-1	+1	707.41	694.02
11	-1	+1	-1	+1	602.03	597.69
12	+1	+1	-1	+1	562.58	550.76
13	-1	-1	+1	+1	848.89	916.48
14	+1	-1	+1	+1	774.51	824.13
15	-1	+1	+1	+1	687.45	685.94
16	+1	+1	+1	+1	616.12	604.79

SAMPLE CALCULATION FOR EFFECT ANALYSIS AND STATISTICAL TESTS

- The levels of the variables are shown in ***Table 1***.
- The ***design matrix*** may now be used to develop a ***calculation matrix*** with columns for two, three and four factor interaction effects.
- These columns are obtained by taking all possible products of the main variable columns in the design matrix.
- Moreover, average of the response (avg. y_i) over the replicates is calculated and also listed.
- The difference (d_i) between the values of the two replicates is also found.

SAMPLE CALCULATION FOR EFFECT ANALYSIS AND STATISTICAL TESTS

- The numerical values of effects may be calculated using the ***calculation matrix*** in ***Table 3***.
- To find the value of a particular effect the column of avg. y_i is multiplied with the column associated with that particular effect.
- All the elements thus obtained are then summed and then divided by half the number of unique data points.

SAMPLE CALCULATION FOR EFFECT ANALYSIS AND STATISTICAL TESTS

Table 3 Calculation Matrix

Test	1	2	3	4	12	13	14	23	24	34	123	124	134	234	1234	avg y_i	d_i
1	-1	-1	-1	-1	+1	+1	+1	+1	+1	+1	-1	-1	-1	-1	+1	462.62	-23.8
2	+1	-1	-1	-1	-1	-1	-1	+1	+1	+1	+1	+1	+1	-1	-1	458.07	-20.9
3	-1	+1	-1	-1	-1	+1	+1	-1	-1	+1	+1	+1	-1	+1	-1	559.84	5.3
4	+1	+1	-1	-1	+1	-1	-1	-1	-1	+1	-1	-1	+1	+1	+1	581.02	-25.5
5	-1	-1	+1	-1	+1	-1	+1	-1	+1	-1	+1	-1	+1	+1	-1	545.98	14.0
6	+1	-1	+1	-1	-1	+1	-1	-1	+1	-1	-1	+1	-1	+1	+1	550.94	7.1
7	-1	+1	+1	-1	-1	-1	+1	+1	-1	-1	-1	+1	+1	-1	+1	541.27	5.4
8	+1	+1	+1	-1	+1	+1	-1	+1	-1	-1	+1	-1	-1	-1	-1	540.22	10.0
9	-1	-1	-1	+1	+1	+1	-1	+1	-1	-1	-1	+1	+1	+1	-1	742.70	-46.4
10	+1	-1	-1	+1	-1	-1	+1	+1	-1	-1	+1	-1	-1	+1	+1	700.72	13.4
11	-1	+1	-1	+1	-1	+1	-1	-1	+1	-1	+1	-1	+1	-1	+1	599.86	4.3
12	+1	+1	-1	+1	+1	-1	+1	-1	+1	-1	-1	+1	-1	-1	-1	556.67	11.8
13	-1	-1	+1	+1	+1	-1	-1	-1	-1	+1	+1	+1	-1	-1	+1	882.68	-67.6
14	+1	-1	+1	+1	-1	+1	+1	-1	-1	+1	-1	-1	+1	-1	-1	799.32	-49.6
15	-1	+1	+1	+1	-1	-1	-1	+1	+1	+1	-1	-1	-1	+1	-1	686.70	1.5
16	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	610.45	11.3

SAMPLE CALCULATION FOR EFFECT ANALYSIS AND STATISTICAL TESTS

- Thus the main effect of variable 1 may be calculated as follows:

$$E_1 = \frac{1}{8}[(avg\ y2 - avg\ y1) + (avg\ y4 - avg\ y3) + \ldots$$

$$+ (avg\ y14 - avg\ y13) + (avg\ y16 - avg\ y15)]$$

$$= \frac{1}{8}[(458.07 - 462.62) + (581.02 - 559.84) + \ldots$$

$$+ (799.32 - 882.68) + (610.45 - 686.7)]$$

$$= -28.03$$

SAMPLE CALCULATION FOR EFFECT ANALYSIS AND STATISTICAL TESTS

- 100 (1-α)% confidence interval for the true mean effect may then be found using the following:

$$C.I. = E_i \pm t_{\nu,\, 1-\alpha/2}\, s_{effect}$$

where, ν is the degrees of freedom for the case in hand (ν = 16 for the present case).

SAMPLE CALCULATION FOR EFFECT ANALYSIS AND STATISTICAL TESTS

- The sample variance of an effect in the above case is given by

$$s^2_{effect} = 4\ s^2_p/N$$

where, N is the total number of data points (in the above case N = 32).

SAMPLE CALCULATION FOR EFFECT ANALYSIS AND STATISTICAL TESTS

- The pooled sample variance (s_p^2) may be found by using the following relation:

$$s_p^2 = \sum_{i=1}^{m} \frac{d_i^2 / 2}{m}$$

where, m is the number of unique combinations of the variables (16 in this case).

SAMPLE CALCULATION FOR EFFECT ANALYSIS AND STATISTICAL TESTS

- Hence,

$$s^2_p = [1/(16x2)]\ [(-23.8)^2 + \ldots + (11.3)^2] = 11707.27/32 = 365.85$$

$$s^2_{effect} = (4/32)s^2_p = s^2_p/8 = 45.73$$

- Therefore,

$$s_{effect} = 6.76$$

SAMPLE CALCULATION FOR EFFECT ANALYSIS AND STATISTICAL TESTS

- Thus, 95% confidence interval for the true mean of main effect of variable 1 is given by

$$\text{C.I.} = E_1 \pm t_{16,\,0.975}\, s_{effect}$$

$$= -28.03 \pm (2.120)(6.76)$$

$$= -28.03 \pm 14.33$$

$$= -42.36,\ -13.7$$

SAMPLE CALCULATION FOR EFFECT ANALYSIS AND STATISTICAL TESTS

- Thus, we are 95% confident that the true mean effect of variable 1 lies in the interval from -42.36 to -13.7.
- Since this interval does not include zero, we may conclude that the effect is statistically significant.

FACTORIAL DESIGN ANALYSIS

Significant Effects

- The numerical values of all the effects (values in **red** represent the significant effects) for each are shown in ***Table 4***

  - **1 represents the main effect of variable 1;**
  - **12 represents the 2-factor interaction between variables 1 and 2;**
  - **123 represents the 3-factor interaction between variables 1, 2 and 3;**
  - **1234 represents the 4-factor interaction between variables 1, 2, 3 and 4.**

FACTORIAL DESIGN ANALYSIS

Table 4 Effect Values

Effect	1	2	3	4	12	13	14	23
Torque (N-cm)	-28.0	-58.3	62.0	167.4	3.2	-10.9	-33.2	-41.7
Thrust (N)	-28.3	4.6	61.8	-50.1	-57.7	-26.1	-1.4	-6.4
Effect	**24**	**34**	**123**	**124**	**134**	**234**	**1234**	
Torque (N-cm)	-109.6	32.8	-2.9	-1.7	-7.7	17.2	5.0	
Thrust (N)	21.7	10.7	7.1	-6.6	-6.1	-13.4	19.0	

Values in **red** represent the significant effects

FACTORIAL DESIGN ANALYSIS

Table 5 Significant Effect Summary

Significant effects	*Main*	*2-Factor Interactions*
Torque	**Grind, Finish, Speed, Cutting fluid**	**Cutting fluid-Grind, Cutting fluid-Finish, Cutting fluid-Speed, Finish-Speed**
Thrust	**Grind, Speed, Cutting fluid**	**Grind-Finish, Grind-Speed**

FACTORIAL DESIGN ANALYSIS

Significant Effect Summary

- ***Table 5*** presents the results of the effect analysis in a summarized form.
- When a main effect is significant, this means that change from the low to high level of that variable increase (+ve effect) or decrease (-ve effect) the response (torque or thrust).

FACTORIAL DESIGN ANALYSIS

Significant Effect Summary

- Since so many 2-factor interactions are significant, the main effects must be interpreted with great caution because these effects are averaged over high and low levels of other variables
- For example, the main effect of variable 1 is averaged over the high and low levels of other variables, namely 2, 3, and 4.

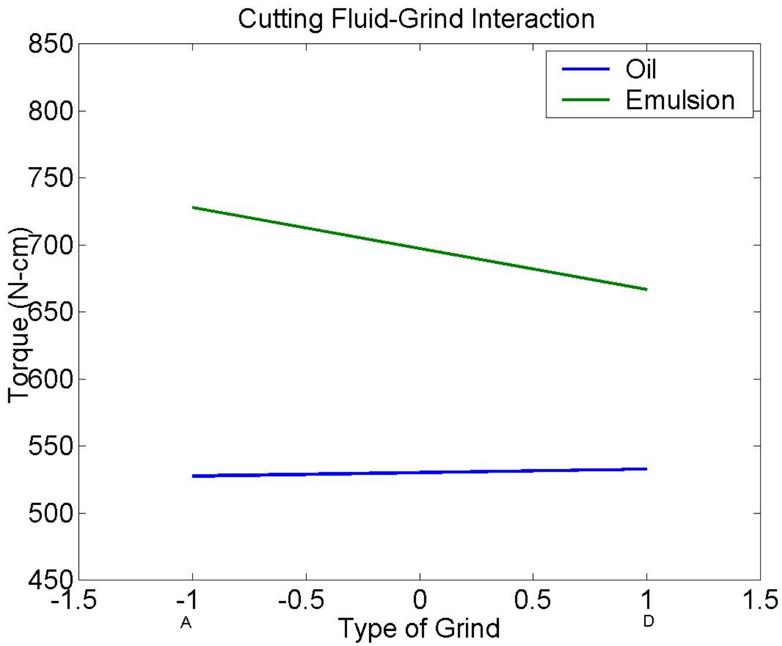
FACTORIAL DESIGN ANALYSIS

Significant Two Factor Interaction Effect Interpretation

- Two-way diagrams lend ease to the interpretation of two and three factor interaction effects.
- The two-way diagrams for all the significant interaction effects are shown in Figures 3 through 8.

FACTORIAL DESIGN ANALYSIS

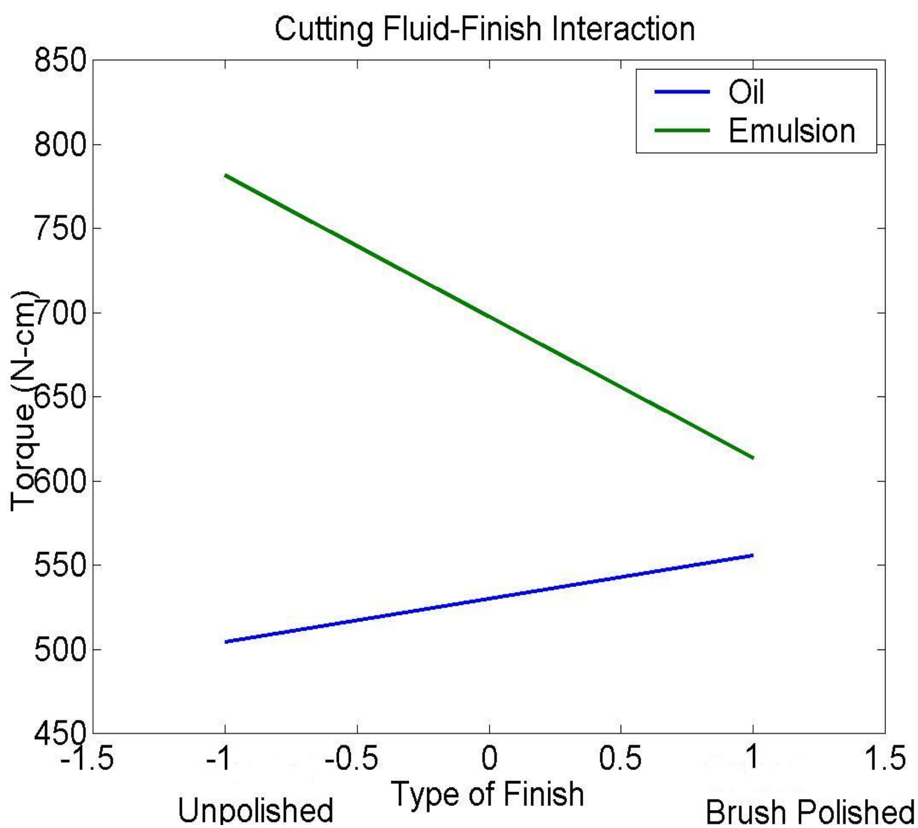
Figure 3 Two-Factor Interaction for Torque: Cutting Fluid-Grind



- Grind D was found to lead to lower torques as compared to Grind A, when Emulsion was used.
- When Oil was used, the difference caused by grind was insignificant.

FACTORIAL DESIGN ANALYSIS

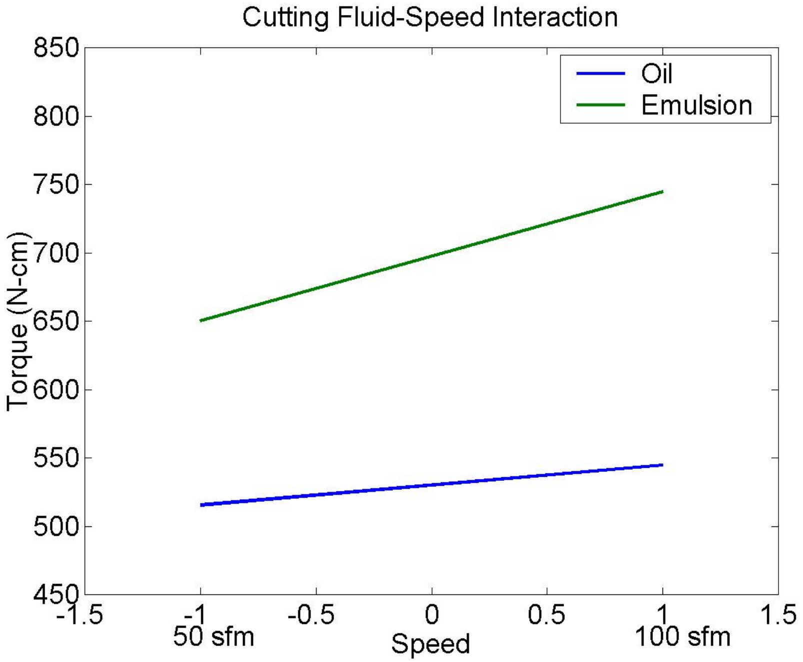
Figure 4 Two-Factor Interaction for Torque: Cutting Fluid-Finish



- Brush-polished finish leads to more robust torque signals i.e., change in cutting fluid does not have much affect on the torque signals experienced with brush-polished tap finishes.

FACTORIAL DESIGN ANALYSIS

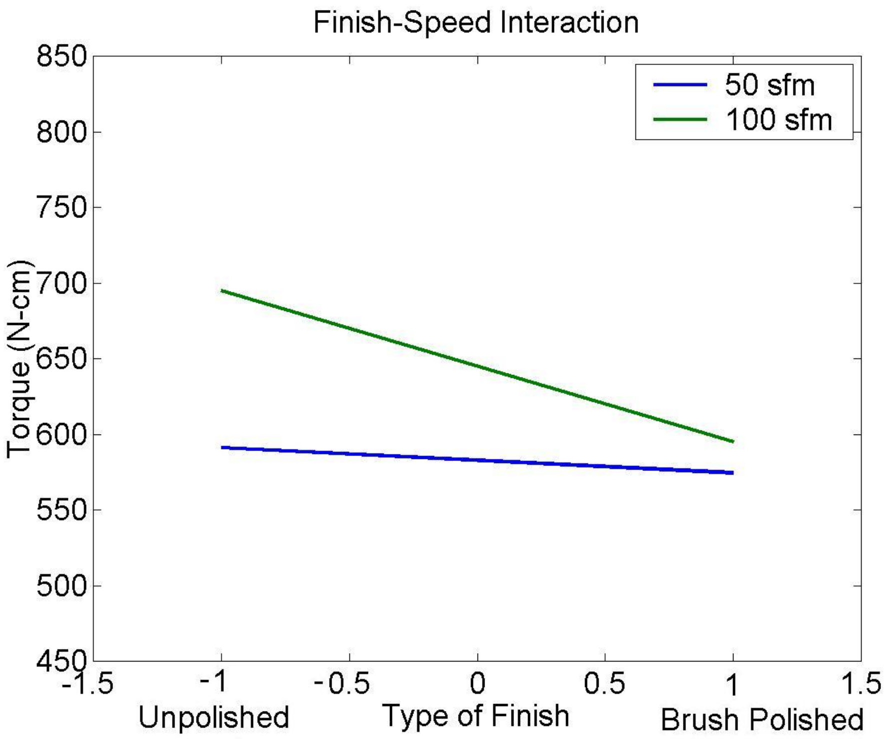
Figure 5 Two-Factor Interaction for Torque: Cutting Fluid-Speed



- Lower torques were experienced while doing the experiments at 50 sfm as compared to 100 sfm, though Oil has a more pronounced effect on torque for experiments done at 100 sfm.

FACTORIAL DESIGN ANALYSIS

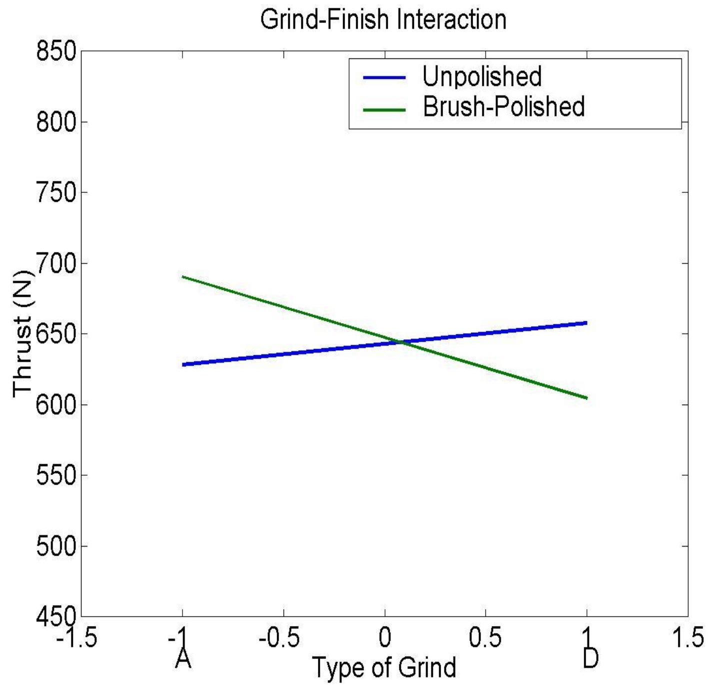
Figure 6 Two-Factor Interaction for Torque: Finish-Speed



- Brush-polished finish leads to more robust torque signals i.e., change in speed does not have much affect on the torque signals experienced with brush-polished tap finishes.

FACTORIAL DESIGN ANALYSIS

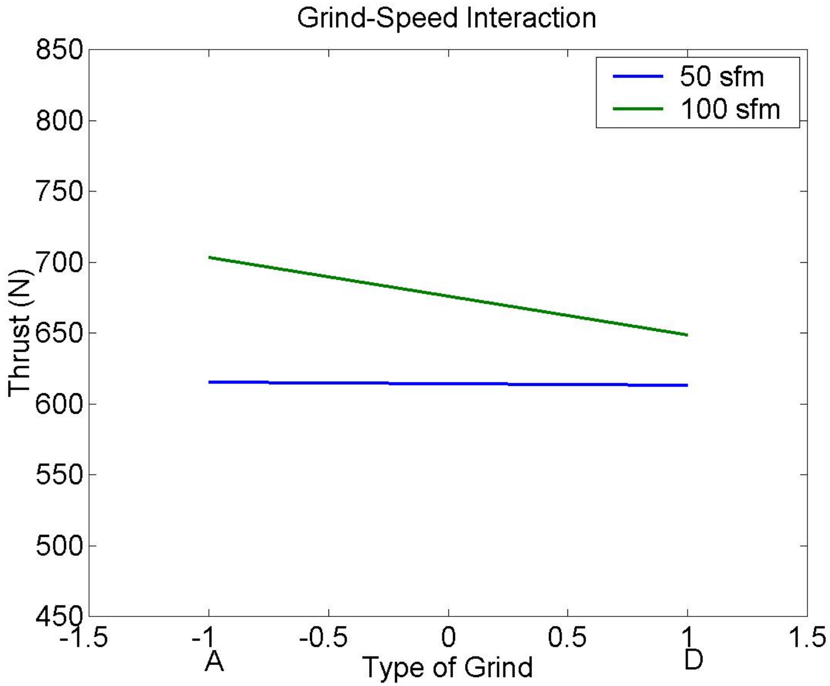
Figure 7 Two-Factor Interaction for Thrust: Grind-Finish



- For brush-polished taps, Grind D was found to lead to lower thrusts as compared to Grind A.
- For unpolished taps, Grind A was found to lead to lower thrusts.

FACTORIAL DESIGN ANALYSIS

Figure 8 Two-Factor Interaction for Thrust: Grind-Speed



- Lower thrusts were experienced while doing the experiments at 50 sfm as compared to 100 sfm.
- The use of Grind D leads to lower thrusts at 100 sfm.
- At 50 sfm, the effect of Grind is insignificant.

OVERALL CONCLUSIONS

- Grind D was consistently found to lead to lower torques as compared to Grind A.
- Polished finish leads to more robust torque signals, i.e., change in variables like grind, speed and cutting fluid do not have much affect on the torque signals experienced with polished tap finish.

OVERALL CONCLUSIONS

- Using oil at higher speeds is more beneficial. On an average, there was 15.2% reduction in torque by using oil over emulsion.
- Grind D was found to lead to lower thrusts as compared to Grind A, for polished taps.
- Lower thrusts were experienced while doing the experiments at 50 sfm as compared to 100 sfm.