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Design and stress analysis of broach tool for splines

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ABSTRACT
Broaches are used for machining either internal or external surface (i.e. sizing of holds and cutting of serrations, straight or helical planes, gun rifling and key ways). In this work a broach cutting tool is design to perform internal splines of synch shuttle transmission for flange coupling. Broaching is a machining process in which a cutting tool, having multiple transverse cutting edges, is pushed or pulled through a hole or surface to remove metal by axial method. It is capable of production rates as much as 25 times faster than any traditional metal removing methods In this work a broach cutting tool is design to perform internal splines on sleeve main shaft. A sophisticated ANSYS 11 (FEM) package shall be used to analyze the displacements and stresses present in broach cutting tool. Further the solid model can be used to perform the finite element analysis which would help in knowing the characteristic of the broach tool under various cutting loads.

I. Introduction

Broaching is commonly used for machining of internal or external complex profiles that are difficult to generate by other machining processes such as milling and turning. Originally, broaching was developed for noncircular internal profiles and keyways. The process is very simple, and decreases the need for talented machine operator while providing high production rate and quality. Because of the straight noncircular motion, very high quality surface finish can be obtained. In addition, roughing and finishing operations can be completed in one pass reducing total cycle time. The main disadvantage of broaching is the inflexibility of the process in terms of process parameters. In broaching, all machining conditions, except the speed, are defined by the tool geometry, and thus, once a tool is designed it is impossible to change any process parameters such as depth of cut or chip thickness. This makes tool design the most important aspect of the broaching process. For improved productivity and part quality with reduced process cost, broach tools must be designed properly. In this paper, an approach for optimal design of broaching tools is presented with applications. This approach can be used for optimal design of broaching tools for a given part geometry and material.

II. Broach tool design

When compared to other cutting tools such as a milling cutter, a broach is many times costlier. Any small error committed in the design of a milling cutter or a turning tool may not result in the rejection of part or the tool. At the most it may result in reduced tool life or lesser productivity. But in case of the broaches, such a mistake may result in the breakage of tool or rejection of parts. It is for this reason that broach design should be done more precisely and accurately.

III. Cutting factors and parameters

The cutting elements of broach teeth are shown in Figure.1. The face angle or hook angle is equivalent to the rake angle of single point tools and depends upon the material to be cut, the back off angle is chosen independent of work material to ensure good cutting conditions by reducing friction between the tooth flank and the machined surface. The land (g) provides the necessary strength for the tooth the chip space with radius (r–Gullet) facilitates formation of chips into convenient shape and accommodates the trapped chips the distance P between successive teeth is pitch, the difference in heights of successive teeth forms cut per tooth or rise Per tooth.

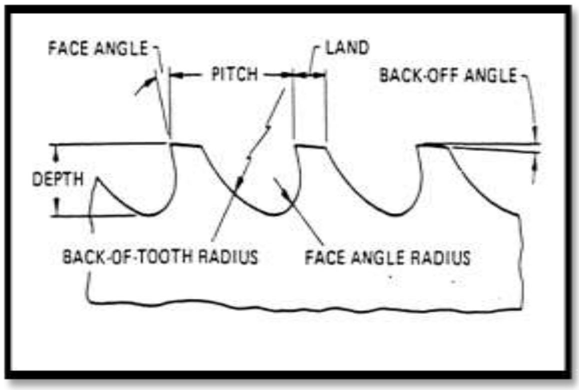


Figure.1: Cutting elements of Broach

Modes of cutting in broaching :(a) Full-form; (b) generation; (c) staggered;(d) Alternate and multiplesided

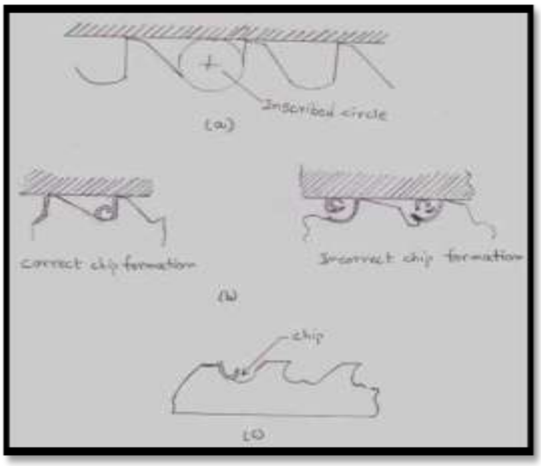
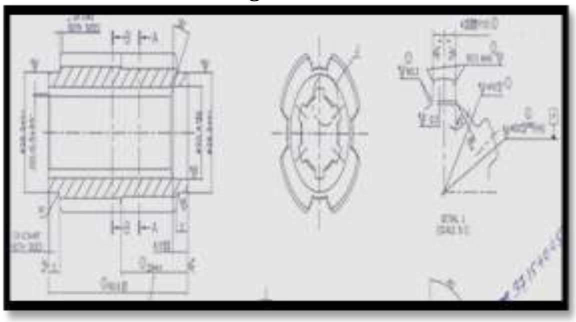


Figure.2: Design for chip space in a broach

IV. Design procedure

Proper observation of the component drawing leads us to the following data:



Major Dia. D = 20 mm
Minor Dia. d = 16 mm
No. of splines S = 6
Spline width W = 4.0 + 0.01 mm
Length of the splines I = 60 mm
Hardness = 35 HRC

Parameter description		Value
Riset/tooth	-	0.04 mm
Pitch	-	10.46 mm
Rake angle (Roughing)	-	15 deg
Rake angle (finishing)	-	7 deg
Land	-	3.5 mm
Depth of tooth	-	4 mm
Radius at gullet	-	2 mm
Length over teeth	-	977 mm
Length of front pilot	-	80 mm
Length of rear pilot	-	60 mm
Front pilot dia	-	43.4 mm
Rear pilot dia	-	43.4 mm
Pull end	-	J – 32 DIN 1417
Rear end	-	L – 32 DIN 1417
Total length of tool	-	1417 mm
Specific cutting force	-	380 kgf / mm^2
Total Broaching force	-	8025 kg
Number of roughing teeth	-	88
Number of finishing teeth	-	5

Table 4.1

V. Broaching tool design for internal splines Results:

Input data

PART NAME: SLEEVE MAIN SHAFT	
PARAMETER	**VALUE**
Major Dia. D	20 mm
Minor Dia. D	16 mm
No. of splines S	6
Spline width W	4 mm
Length of the splines I	60 mm
Hardness	35 HRC

Output data

PARAMETER	VALUE
PITCH	10..457
LAND	2.61
DEPTH	3.91
TOTAL NO. OF ROUGHING TEETH	88
TOTAL NO. OF FINISHING TEETH	5
FACTOR OF SAFETY	3.25
BROACHING FORCE	80825 Kg/mm
INDUCED STRESS IN TOOL AT MIN. AREA	12.36 Kg/mm²

The rake angles of tool for 12°, 15° and 18° and pitch of 9.68 mm, 10.457 mm and 11.23 mm are considered for various values of depth of Cut (rise / tooth), the values of length of the tool over teeth, total length of the tool, specific cutting force, total Broaching force and load per tooth were recorded with the help of 'C' program and the results are tabulated.

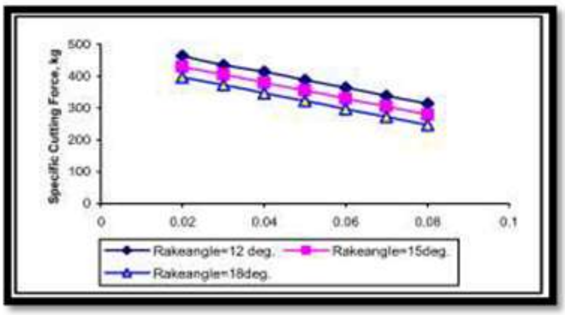


Figure.4: Variation of specific cutting force Vs. Rise/Tooth

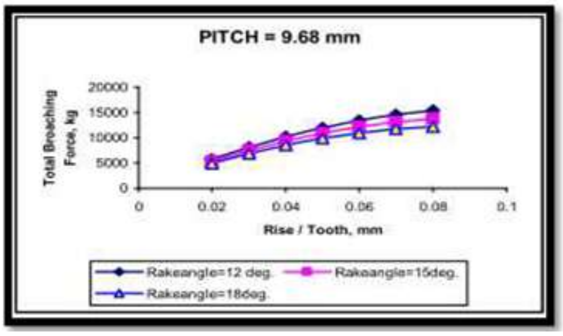


Figure.5: Variation of Total broaching force Vs. Rise/ Tooth

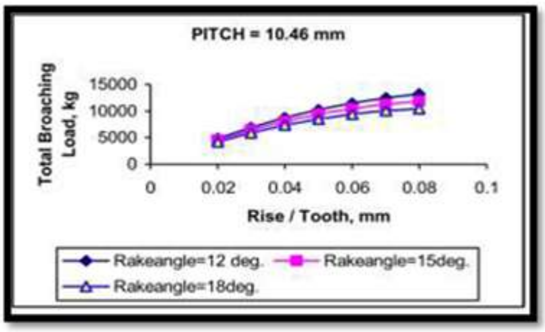


Figure.6: Variation of Total broaching force Vs. Rise/tooth

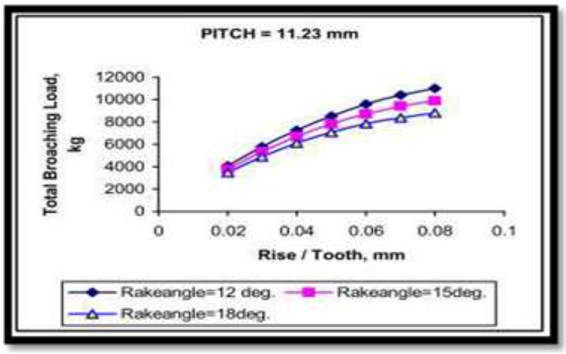


Figure.7: Variation of total broaching force Vs. Rise/tooth

VI. STRESS DISTRIBUTION AND NODAL DISPLACEMENT USING FINITE ELEMENT ANALYSIS

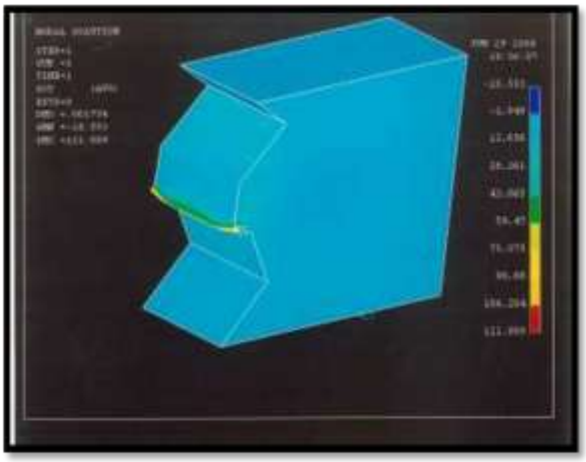


Figure.8: Cutting tooth with Finite elements

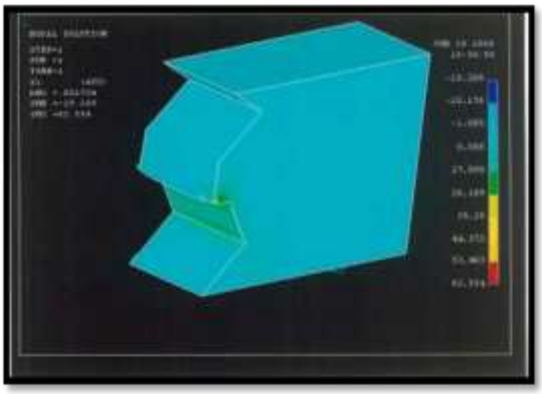


Figure.9: 1st Principle stress distribution S1

The below table shows rise/tooth mm, load/tooth, stress SX, stress SY, stress SXY, stress S1, stress S2, N/mm2 and deflection, mm for rake angle 15°,12° and 18°.

PITCH : 10.46mm				RAKE ANGLE : 15 deg.			
	MAXIMUM VALUES						
Rise/ Tooth mm	Load/ Tooth N	Stress SX N/mm^2	Stress SY N/mm^2	Stress SXY N/mm^2	Stress S1 N/mm^2	Stress S2 N/mm^2	Deflection mm
0.02	472.29	194.36	33.64	64.32	217.249	32.519	0.03102
0.03	668	196.445	45.12	64.82	218.607	34.37	0.0321
0.04	836	198.78	61.02	65.75	219.965	36.221	0.0337
0.05	976.5	199.78	72.05	66.32	221.109	37.963	0.0348
0.06	1088.9	200.849	79.82	66.52	221.919	39.273	0.03581
0.07	1174.2	201.918	87.57	66.82	222.73	40.583	0.3562
0.08	1236.6	202.592	92.48	67.31	223.245	41.429	0.03681

PITCH : 10.46mm				RAKE ANGLE : 12 deg.			
	MAXIMUM VALUES						
Rise/ Tooth mm	Load/ Tooth N	Stress SX N/mm^2	Stress SY N/mm^2	Stress SXY N/mm^2	Stress S1 N/mm^2	Stress S2 N/mm^2	Deflection mm
0.02	509.2	195.25	44.92	64.79	217.82	34.80	0.03059
0.03	722.6	197.89	55.21	65.50	219.25	36.81	0.03171
0.04	908	199.95	66.49	65.21	220.92	38.09	0.03283
0.05	1066.9	200.88	79.15	65.98	221.10	39.35	0.03387
0.06	1197.8	202.03	89.35	67.59	222.64	40.59	0.03432
0.07	1301.3	203.29	97.55	68.72	223.78	42.31	0.03494
0.08	1377.2	204.11	103.52	69.52	224.41	43.34	0.03591

PITCH : 10.46mm						RAKE ANGLE : 18 deg.	
		MAXIMUM VALUES					
Rise/ Tooth mm	Load/ Tooth N	Stress SX N/mm^2	Stress SY N/mm^2	Stress SXY N/mm^2	Stress S1 N/mm^2	Stress S2 N/mm^2	Deflection mm
0.02	436	193.85	24.64	63.78	216.8	30.289	0.0321
0.03	612	195.73	38.72	64.42	218.02	32.92	0.03321
0.04	763	197.56	54.56	64.12	219.428	34.607	0.03382
0.05	885.4	198.62	63.87	65.72	220.65	36.28	0.03476
0.06	980	199.67	68.46	65.86	221.23	38.15	0.03536
0.07	1042	200.32	78.32	66.34	221.96	39.21	0.03686
0.08	1087	200.85	81.43	66.98	222.32	40.02	0.03762

Below are the variations of stresses SX, SY with respect to Rise/tooth

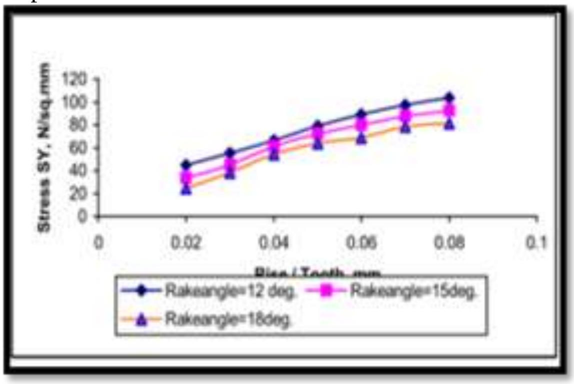


Figure:10: Variation of stress SY Vs. Rise/tooth

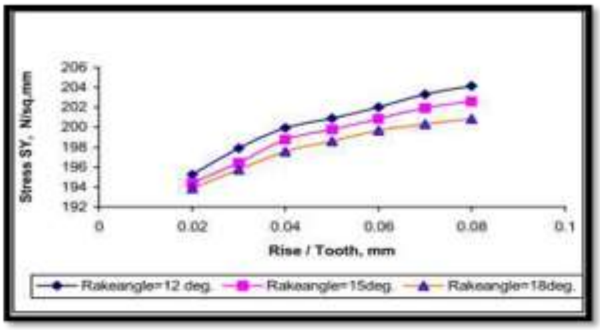


Figure:11: Variation of stress SX Vs. Rise/tooth

VII. Conclusion

- The variation of cutting force per tooth is constant for different pitch values, for a given rake-angle.
- The total Broaching force varies with pitch value for a given rake angle due to the variations in number of teeth in engagement.
- The stress plot against depth of cut shows uniform increase of stresses, the stresses are increasing with decreasing of rake angles due to higher cutting forces.
- The deflection of the tooth is higher for higher rake angle. This is because of the reduction in included angle of the tooth.
- The rake angle influencing the total broaching force and force on cutting tooth. Hence very care should be taken while re-sharpening the tooth tool to maintain the designed rake angle on the profile of the tooth.

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