The Design and Manufacture of Plastic Gears

Part II

Machining, Installation and Gear Sound Measurement

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ABSTRACT

Advancements in machining and assembly techniques of thermoplastic gearing along with new design data has lead to increased useage of polymeric materials. Information on state of the art methods in fabrication of plastic gearing is presented and the importance of a proper backlash allowance at installation is discussed. Under controlled conditions, cast nylon gears show 8-14 dBA, lower noise level than three other gear materials tested.

Introduction

In Part I, which was presented in the May/June issue of *Gear Technology*, the latest design parameters for endurance strength as a function of diametral pitch, pressure angle, pitch line velocity, lubrication and life cycles were reported.

Machined gears of cast or extruded thermoplastics (such as nylons, acetals, and UHMWPE) ranging in size from 50 mm to over 2 meters (2"-84") in diameter are increasingly used for power transmission applications. The plastic gear blanks are machined to required dimensions and then cut by hobbing, shaping, form milling or other methods.

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Some information pertaining to machining plastic gearing is available.(1-4) Most metal working equipment can be adapted or modified to fabricate plastic gearing.

Over the years, empirical data in improved techniques for machining plastics has developed. The improvements in manufacturing and installation, along with new design data resulted in increased utilization of polymeric materials and in prevention of premature failures.

Tools and techniques for machining plastics are illustrated. Emphasis is placed on variations between machining plastic and metal gears. The importance of proper installation and backlash allowance are discussed.

Low acoustic impedance(5) and sound dampening characteristics make thermoplastic gearing a choice in combating industrial noise pollution. Sound measurements were conducted on cast nylon 6, bronze, phenolic and cast iron gears, and the results reported.

Plastic Gear Construction and Fabrication

Extruded or cast gear blanks are produced sufficiently oversize to allow for machining to the finished dimensions of the gear.

Gears up to 20 cm (8") outside diameter are often constructed entirely of extruded thermoplastic or cast nylon; however, consideration must be given to the gear configuration and type of service. For plastic gear rings exceeding 20 cm in diameter, or for gears in relatively severe service, it is suggested that a metal hub be utilized. The inside diameter of the gear ring blank must be machined accurately to match the frame diameter, allowing an interference fit when assembled. In addition, the plastic gear ring must be securely bolted to the frame to prevent movement.

General Machining

Normally, standard metal working equipment can be effectively used for machined thermoplastic gears. Therefore, machining techniques for engineering plastic gears are similar to those employed for metals; however, there are several important differences due to certain characteristics of polymeric materials. For optimum results, certain characteristics unique to thermoplastic must be recognized and allowances for these made. One of these characteristics is the generation of frictional heat. Generated heat must be kept to a minimum or removed by coolants. Tools must be kept sharp and provided with generous clearances. In general, very high speeds with relatively low feeds produce the best results. Also, polymers exhibit a relatively low modulus of elasticity and are rather flexible when compared to metals. Provision must be made to prevent flexing of stock away from the cutting tools, and clamping or gripping pressures must be held to a minimum. Clamping pressures and fixtures must not overstress the material, yet must be adequate to prevent chatter. Between rough and finish machining, a 24 to 48 hour normalizing at room temperature is a popular procedure. Large plastic parts such as gear rings and/or gear segments must be securely fastened to a metal hub or frame prior to final machining.

Tolerances of plastic gears must be liberal in comparision to metals. As an example, a 25.4 mm (1") diameter bore might be specified for a tolerance of ±0.05 mm (±0.002"). Variations in plastic materials must be considered when developing specifications for gears.

Drilling and Reaming

Drilling holes in plastic can cause difficulties not normally encountered with metals. The melting point of engineering thermoplastics in the range of 175° to 265°C (347/510°F) is considerably lower than metals, so the use of dull drills or drilling "dry" must be avoided. The use of adequate coolant with frequent withdrawal of the drill to prevent chip build-up will prevent this potential problem. Fig. 1 and Table 1 show typical drill design and speed in RPM for drilling plastics. Normal feed rates are 0.1-0.4 mm (0.004" to 0.015") per revolution. Large diameter holes are usually machined in two or more stages.

The relative softness of plastic materials require the use of oversize reamers to allow for close-in of the hole. Speed and feed rates should approximate those used for drilling, with a minimum removal of 0.12 to 0.25 mm (0.005"-0.010"). The use of coolant will also aid in improving surface finish.

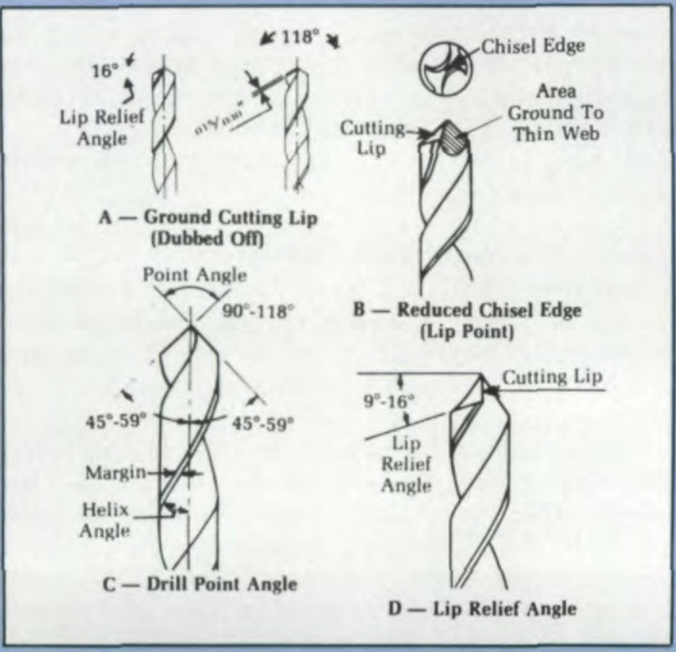

Fig. 1 – Drill Design

Table 1: Drill Speed Size Chart

Drill Sizes (USAS B94.11 1967)	RPM
No. 60 thru 33	5,000
32 thru 17	3,000
16 thru 1	2,500
1.6 mm (1/16")	5,000
3.2 mm (1/8")	3,000
4.8 mm (3/16")	2,500
6.4 mm (1/4")	1,700
8.0 mm (5/16")	1,700
9.5 mm (3/8")	1,300
11.1 mm (7/16")	1,000
12.7 mm (1/2")	1,000
A thru D	2,500
E thru M	1,700
N thru Z	1,300

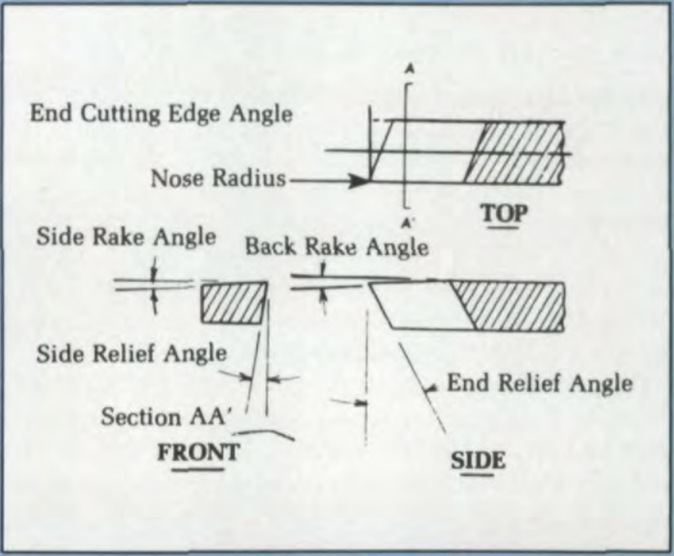

Fig. 2 – Cutting Tool Design

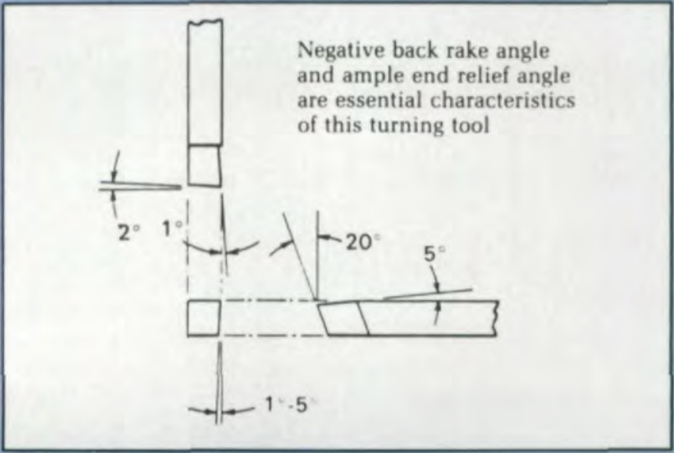

Fig. 3 – Cutting Tool Design

Turning and Boring

Plastic blanks are usually machined at cutting speeds of 600 to 900 surface ft. per minute. Roughing cuts up to 10 mm (3/8") at 0.4 mm feed (0.15" per revolution, and finishing cuts 1.5-3.0 mm (1/16" to 1/8") at 0.08-0.18 mm (0.003" to 0.007") per revolution are suggested as starting rates. Proper clamping pressure, fixturing, cutting tools and coolant combine to result in trouble-free machining.

Fig. 2 and 3 show typical carbide cutting tool design. Fig. 4 shows typical high speed steel cut-off tool design.

Gear Cutting

Hobbing, shaping and form milling are methods commonly used for cutting plastic gear teeth. Tooling and fixtures should be similar to those used for metal gears. Standard high speed steel cutters can be used satisfactorily to cut gear teeth in plastics. Carbide hobs, however, will exhibit longer cutting life and are preferred for long production runs and for gears with many teeth. Selection of appropriate speeds and feeds for milling or hobbing plastics will depend largely on judgement gained from experience. Suggested feeds and speeds are offered in Table 2 only as a guide to what may be considered ordinary practice. Table 3 is a checklist describing various machining difficulties and causes.

Gear finishing operations such as shaving, grinding, honing or lapping are normally not utilized for plastic gears. The tooth surface finish from gear hobbing and/or shaping is adequate for most applications precluding the need for subsequent finishing.

Installation and Backlash Allowance

Properly designed, manufactured and installed plastic gearing work well in practice and will show minimal wear.

One of the most frequent design errors made in converting from a metal gear to a plastic gear is not allowing sufficient backlash. Insufficient backlash in plastic gearing can cause heat buildup and tooth deflection which lead to interference and premature failures including wear, pitting, tooth profile deformation and melting(5).

Backlash of metal gearing was established using generally recognized tolerances for gear tooth and center distances, and lubricating film thickness. For plastic gearing, in addition, thermal expansion in tooth thickness, elastic deflection and creep deformation of the teeth at operating temperatures are significant enough to be taken into consideration.

Table 2: Gear Cutting Speeds and Feeds

Cutting Method	Surface Cutting Speed	Feed Rate
Hobbing	3.05-4.57 m/s (600-900 ft./min.)	1.5-3.0 mm/rev. (0.060"-0.120"/rev.)
Shaping	0.9-1.0 m/s (175-200 ft./min.)	.13-.25 mm/stroke (0.005"-0.010"/stroke)
Milling	3.05-4.57 m/s (600-900 ft./min.)	75-200 mm/min. (3"-8"/min.)

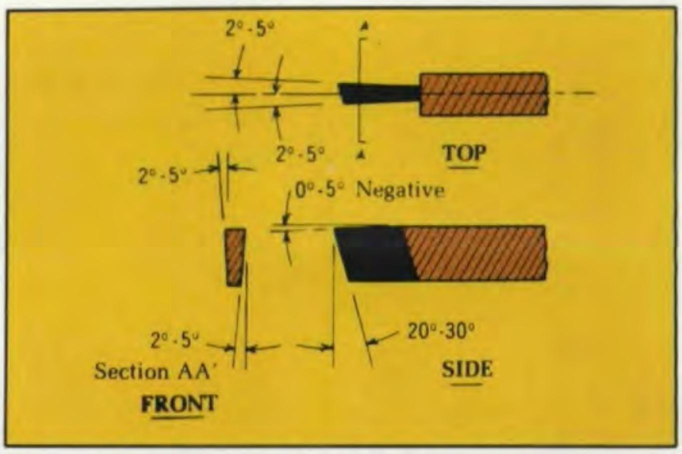

Fig. 4 – Cut-Off Tool Design

The following formula can be utilized to calculate the necessary operating backlash for thermoplastic gearing in open air systems.

Backlash Allowance
$= 0.100''/P$ Eq. (1)
where P = diametral pitch

In an enclosed system, thermal expansion of pitch radius due to temperature increase in the gear box is to be added to the backlash allowance, then:

Backlash Allowance
$= 0.100''/P + 1.82\, D_p \bullet \Delta T \times 10^{-5}$ *Eq. (2)*
where D_p = pitch diameter

The backlash allowance is provided in order of preference, by center distance adjustment, or by tooth thinning of the mating metal gears, or by tooth thinning of the plastic gears, or by any combination of the three.

When installing thermoplastic gears, care must be taken to insure that the gear mesh has been checked for the appropriate backlash prior to operating the gear system. It is suggested that the plastic gear and the mating gear be checked at 90° intervals through one complete rotation to insure both gears are running true and are not mounted on bent shafts or defective bearings.

Gear Sound Measurement

Gear noise is a problem in many industries, but complex factors are involved in noise generation. The design of the entire system, for example, must be thoroughly investigated to isolate noise sources which can then be addressed with suppression techniques.

Thermoplastic gearing involves three acoustic implications. First, a plastic/metal gear mesh will generate much lower impact noise than a metal/metal gear mesh, due to sound dampening characteristics of polymeric materials. Secondly, the mesh impact is further reduced by multiple pairs of teeth sharing the load. Third, since the material has a lower acoustic impedance, sound transmission is poor and any noise waves generated are well attenuated.

Sound levels of cast nylon 6 (filled with MoS_2), grey cast iron (AGMA 30), bronze (SAE CA932A) and phenolic laminate (ANSI/ASTM D709, II Grade C) for 10P gears meshing with a steel driving pinion was measured in dBA at a pitch line velocity of 10.2 m/s (2,000 fpm) and at different torque levels. With the outer cover of the test machine removed, a monitoring microphone was set 30.5 cm (12") from the mesh point of the gears. The center distance of the mating gears was maintained at 88.93 mm (3.501") for all tests.

A sound level meter equipped with piezo-electric microphone, which gives it a frequency range from 20 Hz to 10 kHz was used. The sound meter has built-in A, B, and C weighing networks and conforms to type II of ANSI (American National Standard Institute) S 1.4 – 1971 and IEC (International Electrotechnical Commission) R 123-1961 specifications. The noise amplitude was measured as sound pressure in dB (decible) at the A scale, which is close to the human ear perception. A description of the four-square test machine was given in Part I of this paper.

Sound level in dBA at different torque measurements are illustrated in Fig. 5. When 100 inch-lbs. torque was applied,

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Table 3: Machining Difficulties and Causes

CHECK LIST

DRILLING	
Difficulty	**Common Causes**
Tapered hole	1. Incorrectly sharpened drill 2. Insufficient clearance 3. Feed too heavy
Burnt or melted surface	1. Wrong type drill 2. Incorrectly sharpened drill 3. Feed too light 4. Drill dull 5. Web too thick
Chipping of surfaces	1. Feed too heavy 2. Clearance too great 3. Too much rake (thin web as described)
Chatter	1. Too much clearance 2. Feed too light 3. Drill overhang too great 4. Too much rake (thin web as described)
Feed marks or spiral lines on inside diameter	1. Feed too heavy 2. Drill not centered 3. Drill ground off-center
Oversize holes	1. Drill ground off-center 2. Web too thick 3. Insufficient clearance 4. Feed rate too heavy 5. Point angle too great
Undersize holes	1. Drill dull 2. Too much clearance 3. Point angle too small
Holes not concentric	1. Feed too heavy 2. Spindle speed too slow 3. Drill enters next piece too far 4. Cut-off tool leaves nib, which deflects drill 5. Web too thick 6. Drill speed too heavy at the start 7. Drill not mounted on center 8. Drill not sharpened correctly
Burr at cut-off	1. Cut-off tool dull 2. Drill does not pass completely through piece
Rapid dulling of drill	1. Feed too light 2. Spindle speed too fast 3. Insufficient lubrication from coolant

CUTTING OFF	
Difficulty	**Common Causes**
Melted surface	1. Tool dull 2. Insufficient side clearance 3. Insufficient coolant supply
Rough finish	1. Feed too heavy 2. Tool improperly sharpened 3. Cutting edge not honed
Spiral marks	1. Tool rubs during its retreat (use same fall on cam as rise) 2. Burr on point of tool
Concave or convex surfaces	1. Point angle too great 2. Tool not perpendicular to spindle 3. Tool deflecting (use negative rake) 4. Feed too heavy 5. Tool mounted above or below center
Nibs or burrs at cut-off point	1. Point angle not great enough 2. Tool dull or not honed 3. Feed too heavy
Burrs on outside diameter	1. No chamfer before cut-off 2. Tool dull
TURNING & BORING	
Melted surface	1. Tool dull or heel rubbing 2. Insufficient side clearance 3. Feed rate too slow 4. Spindle speed too fast
Rough finish	1. Feed too heavy 2. Incorrect clearance angles 3. Sharp point on tool (slight nose radius required) 4. Tool not mounted on center
Burns at edge of cut	1. No chamfer provided at sharp corners 2. Tool dull 3. Insufficient side clearance 4. Lead angle not provided on tool (tool should ease out of cut gradually, not suddenly)
Cracking or chipping of corners	1. Too much positive rake on tool (use negative rake) 2. Tool not eased into cut (tool suddenly hits work) 3. Dull tool 4. Tool mounted below center 5. Sharp point on tool (slight nose radius required)
Chatter	1. Tool much nose radius on tool 2. Tool not mounted solidly enough 3. Material not supported properly 4. Width of cut too wide (use two cuts)

MACHINED PLASTIC GEARS . . .

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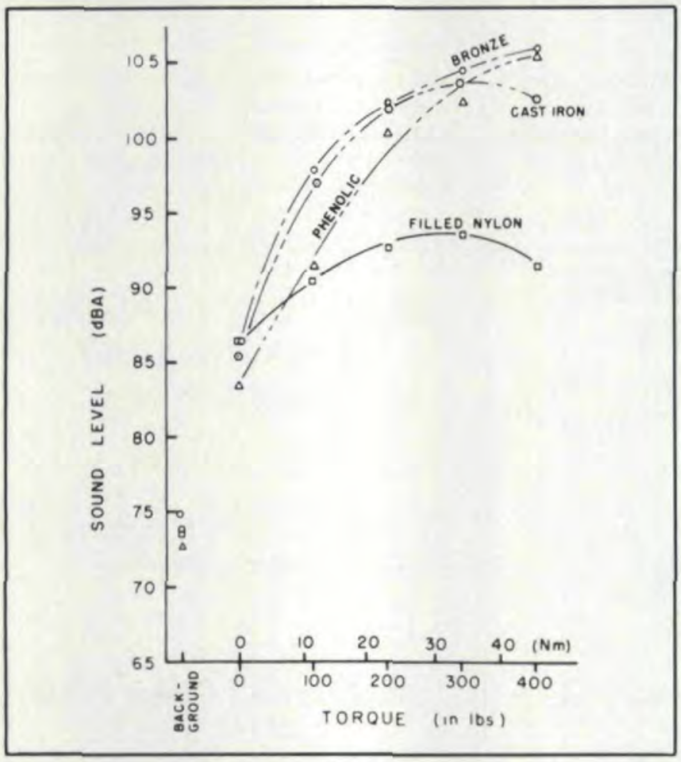

Fig. 5 – Sound Level Vs. Torque

bronze and cast iron test gear noise increased more than 10 dBA. The sound levels of phenolic and bronze gears progressed with increased load. The cast nylon test gear demonstrated its characteristics of noise dampening at all load level test points. A noise reduction of 8 to 14½ dBA was recorded at loads of 22.6, 33.9 and 45.2 N-m (200, 300 and 400 inch-lbs.) in comparison to the other three test gear materials. In actual use, noise reductions in excess of 10 dBA have been recorded in gear trains which incorporate cast nylon gears. Fig. 5 shows a slight dip in sound level at the highest test load of 45.2 N-m (400 inch-lbs.) for cast nylon and cast iron. This is probably due to the increased tooth contact ratio at the higher load. Cast iron is also considered to have some noise dampening qualities.

References

1. FICKEL, H., "Das Spanabhebende Bearbeiten der Kunststoffe," Carl Hanser, Mñchen, 1956.
2. DUDLEY, D. W., "Gear Handbook," McGraw-Hill, New York-Toronto-London, 1962.
3. KOBAYASHI, A., "Machining of Plastics," McGraw-Hill, 1967, New York.
4. The Polymer Corporation, "Nylon Gear Design and Fabrication Manual," BR-36D, 12/83.
5. COTTINGHAM, R.A. and WINNERLING, H.A., "An Advanced Low Noise Stock Feed Tube," Paper Noisexpo, Chicago, 1974.

This paper was previously presented at the 1984 technical meeting of the American Society of Mechanical Engineers.

E-3 ON READER REPLY CARD

TECHNICAL CALENDAR

Sept. 16-18
1985

Gear Noise Course
Ohio State University

This course will cover general noise measurements and analysis, causes of gear noise, gear reduction techniques, dynamic modelling, signal analysis and gear boxes. For further information contact: Mr. Richard D. Frasher, Director, Continuing Education, College of Engineering, 2070 Neil Ave., Columbus, Ohio 43210, (614) 422-8143.

Oct. 14-16
1985

American Gear Manufacturers Fall
Technical Meeting
Fairmont Hotel
San Francisco, CA

For further information contact: AGMA Headquarters, 101 S. Peyton St., Alexander, VA 22314 (703) 684-0211.

Nov. 19-21
1985

Society of Manufacturing Engineers
Gear Processing and Manufacturing
Clinic, Detroit, Michigan.

CALL FOR PAPERS: The Society of Manufacturing Engineers has issued a call for papers for this meeting. The meeting will also include vendor tabletop exhibits. For more information, contact Dianne Leverton at SME (313) 271-1500, ext. 394.

March 17-19
1986

International Conference on Austempered
Ductile Iron, Ann Arbor, Michigan

CALL FOR PAPERS: The organizing committee is seeking papers for this conference. Of particular interest are papers on the engineering properties of Austempered Ductile Iron, quality assurance techniques and experience, product tests, and process and product development case histories based on cost savings, cost avoidance and product improvement. Abstracts to be submitted by August 30, 1985 to: ADI, Gear Research Institute, P.O. Box 353, Naperville, IL 60566. For further Information contact: Dale Breen (312) 355-4200 or Jay F. Janowak (313) 392-7100.