The Tangential Rolling of Crankshaft Fillets

A basic component essential to the successful performance of today's high compression engine is the crankshaft. The loads imposed on the crankshaft have placed great importance on its fatigue life. A prime factor affecting the fatigue life of a crankshaft is the size of the crankshaft fillet radius area. Beginning with the 1964 model production, Oldsmobile Division initiated the practice of tangentially rolling crankshaft fillets. The result has been a 50 per cent increase in fatigue life. The deep fillet rolling process, originally developed in West Germany, was selected by Oldsmobile after several years of investigating various metal working processing methods.

In 1959, a program was started at Oldsmobile to investigate ways to increase the fatigue life of the crankshaft, with particular attention being given to the crankshaft's critical radii. Various manufacturing methods and variations of existing processes pertaining to crankshaft production were studied and tested, including rolling, shot blasting, shot peening, and liquid peening.

The methods and processes studied all had various shortcomings. For example, the shot blasting method for increasing fatigue life was rejected because of the size of the equipment required, the high maintenance costs, and the uneven force reactions on the crankshaft radii subjected to this process. The basic design of a crankshaft also made this process unpredictable and unreliable because of interferences which blocked the various shot and media lines of force—interferences such as those caused by the counterweights and sidewalls of the crankshaft.

Another process considered was undercutting as well as rolling of the fillets. The equipment and tooling concepts available at that time indicated that this process would be impractical. Various tests performed showed that distortions resulted which were unacceptable by Oldsmobile quality standards. Distortion of the crankshaft bearing areas, as well as the entire crankshaft, would require a straightening operation, which ruled out further developmental testing.

Concurrent with the Oldsmobile program to increase crankshaft fatigue life was a program to obtain better control of the radii on crankpin diameters. This program, started in 1956 and successfully completed in 1961, involved running many tests on various type dressers in cooperation with diamond dressing tool companies, diamond tool manufacturers, and machine builders in an attempt to develop the type of dresser required. Everything from cam dressing with grit tools to carbide form rolls, both reciprocating and plunger type, was tried. Impregnated and set-stone formed diamond wheels also were used in the attempt to precision dress the crankpin grinding wheels. Single point diamond tools following a profile cam were put through various tests with a minimum amount of success. Eventually, a rotary diamond wheel dresser following a profile cam was developed. This development was to have a major role in the successful practice of tangentially rolling crankshaft fillets.

Preliminary Tests Proved Worth of Tangentially Rolled Fillets

In early 1962, Oldsmobile's Product Engineering Group was developing a new engine of lightweight design, with prime importance being given to economy of operation and weight-to-horsepower ratio. The developmental program did not call for a major redesign of the crankshaft but did require the crankshaft to have a higher factor of safety. The job of meeting this requirement was given to the Production Engineering Group, which has as one of its responsibilities the processing of crankshafts. Previously tried methods to increase the fatigue life of crankshafts were reinvestigated. New trials were run, new tests were made. The results were not encouraging.

It then was brought to Oldsmobile's
Cold rolling operation provides 50 per cent increase in fatigue life.

attention that a manufacturer in West Germany had developed a process of deep rolling fillets and contours on crankshafts, steering knuckles, and various automotive parts that were being produced in France, West Germany, Holland, and Italy. It also was learned that the crankshaft fillets being rolled were undercut. This application was of interest to Oldsmobile, even though the particular feature of undercutting was not desirable.

The possibility of developing a method for tangentially rolling both the crankpin and main journal radii of the Oldsmobile crankshaft was studied and thought feasible. Arrangements were made to ship crankshafts to West Germany for deep fillet rolling, then return them to Oldsmobile to undergo fatigue tests.

Preliminary tests were performed by the Product Engineering and Design Reliability Groups. One of the tests for fatigue used a resonant tuning fork and associated equipment that was set up to operate at 200 cycles per second to reduce testing time (Fig. 1-top). This equipment enabled the computation of endurance limit curves (Fig. 1-bottom) in a minimum of time.

Once crankshaft fatigue life requirements were established, the exact pressure needed to roll the fillets had to be determined. Several groups of identical crankshafts were rolled at various hydraulic pressures. These shafts then were subjected to resonant fatigue tests to evaluate each group. All tests were run at a constant bending moment, which produced failure in a relatively short period of time. Data from the tests were plotted to determine the effect different rolling pressures had on crankshaft endurance (Fig. 2). Tests also were performed to determine information on physical properties. Samples were used from several crankshafts to measure tensile strength, yield strength, and endurance limit (Fig. 3).

While static tests were being performed, a crankshaft was completely strain gaged for dynamic testing. This crankshaft was placed in an engine which operated at various rpm and throttle openings. The recorded traces were analyzed and maximum operating stresses logged. From the fatigue data and material properties obtained, modified Goodman diagrams were constructed. On these diagrams, dynamic stresses were plotted and safety factors determined.

Based on test results, Oldsmobile knew that a crankshaft with tangentially rolled fillets was reliable and would perform well. Also, the safety factor could be controlled by varying the rolling pressure. This meant that reliability could be controlled. The results of the preliminary tests were used in a further testing program of a more intense nature.

Final Tooling Developed

The concept of the present production equipment used by Oldsmobile to tangentially roll crankshaft fillets was observed firsthand in West Germany and France where rolling equipment of a similar nature was in operation.

The first crankshafts experimentally rolled in the West German plant were returned to Oldsmobile for fatigue tests. Test results indicated that the crankshafts had excellent fatigue life. Inspired by these results, a group of newer model crankshafts was shipped to the West German manufacturer. After being returned to Oldsmobile and tested, no improvement in fatigue life was noted. The reason for the fatigue life increase on the earlier model crankshaft and the lack of it on the newer model crankshaft was not immediately apparent.

After reviewing the various tests and visually inspecting the fillets that had been rolled, it was discovered that the center section of the fillet radius had not been cold worked. This was observed in photomicrographs taken at a magnification of 100X. The problem was resolved into one of rolling tool design. A temporary tooling setup duplicating the West German setup was installed in

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the Oldsmobile plant (Fig. 4). It was soon discovered that the radius of the rolling tool had to be identical to the crankshaft fillet radii and that these radii had to be held. It then was realized that the crankshafts sent from Oldsmobile to West Germany for rolling had been made with tool room type equipment and their fillet radii had been machined to approximately 0.060 in. While the original rolling tools on the German equipment were 0.070 in. This difference caused the rolling tool to straddle the fillet and accounted for the center section of the fillet not being adequately cold worked.

Final tool development was eventually completed by Oldsmobile that gave a 50 per cent increase in fatigue life for the newer model crankshaft. The process of tangential fillet rolling became a reality.

385-Ton Rolling Force Applied to Crankshaft Fillets

The design of the tangential fillet rolling machine is basically quite simple. It consists mainly of a driving unit, two master cranks to drive lever arms that hold the rolling tool assemblies, a loading and unloading device, and necessary hydraulic cylinders and hydraulic supply to apply pressure to the tooling for the cold rolling operation (Fig. 5). The hydraulic cylinders put the lever arms through a moment of leverage and make it possible to apply 624 lb of squeeze pressure to the rolling tool assemblies (Fig. 6).

The tooling used for tangential rolling of the crankshaft fillets consists of an upper and lower cartridge assembly (Fig. 7). The upper cartridge assembly contains the work rollers and the lower cartridge the support, or back-up, rollers.

The work rollers, made of M-2 high speed steel, are machined then hardened through three draws. The final draw is made at a temperature of 900°F. The rollers then are hand polished to a surface finish of 2 to 3 RMS. This RMS surface finish is necessary to prolong the life of the work rollers at the high pressures involved. This surface finish also assures the cold flow of material with the least amount of resistance, provides a good finish in the fillet being rolled, and minimizes the chance of material adhering to the work roller.

The work rollers are 0.610 in. in diameter and are the main working components of the fillet rolling operation. Their basic geometry consists of an 85° included angle that blends into a 0.065-in. radius (Fig. 8-left), which is the mean radius of the Oldsmobile crankshaft's crankpins and main bearing journals. The rollers are machined using a 3/16-in. diameter hole in the center. This allows the roller to be placed upon a mandrel for circular grinding as well as circular relieving and polishing to obtain the RMS finish required. The radii of the rollers are relieved 0.014 in. off center which gives an eccentric relief to the rollers, making the constant radius of 0.065 in. decrease in width to 0.045 in. at the thinnest section. The reason for the arch width varying from the mean radius of 0.065 in. to the relieved radius of 0.045 in. is to give a side thrust, or kneading action, to the material being cold worked.

Work rollers retained in the upper tool cartridge are forced against the back-up roller and into the corner radii of the crankpin or main bearing journal sidewall and diameter when pressure is applied at a work angle of 43° to the vertical centerline (Fig. 8-right). To date, the life of the work rollers has been in excess of 20,000 cycles. The life of the back-up rollers and needle bearing assemblies has not been determined, since no replacements have been made to date. Their life so far is in excess of 50,000 cycles.

Special Tooling Developed for Dressing Grinding Wheels

It is essential that the quality of the crankshaft prior to tangential rolling of the fillets be well within the process tolerances. The crankshaft must be straight, the index and spacing must be of high quality, and the radii prior to rolling must be within ±0.005 in. maximum of the mean dimension. Any attempt to roll crankshafts having tolerances of the arch width varying from the mean radius of 0.065 in. to the relieved radius of 0.045 in. is to give a side thrust, or kneading action, to the material being cold worked.

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Fig. 7—Upper and lower tool cartridges. The upper cartridges (top left) contain the work rollers and the lower cartridges (top right) the back-up rolls. The section drawing shows the construction of the work rollers and back-up rolls.

The upper tool cartridge consists of a magazine that contains a center mandrel, a series of needle bearings, an outer support roll shell, two work rollers, and a work roller retainer. The radius of the work roller is form ground in a backup roller having a Rockwell C hardness between 62 and 63. The two work rollers that contact the back-up roll are retained in a bronze cage in the magazine assembly merely to hold them in position. The hardness of the work rollers is between 58 and 69 Rockwell C.

The lower tool cartridge consists of four center mandrels, four sets of needle bearings, and four back-up rollers set in pairs at a 45° included angle. The centerline of the crankpin or main bearing journal of the crankshaft. Riding in contact with each pair of back-up rolls is another roller approximately 0.500 in. in diameter, which bears tangent against the two work rollers and against the crankpin or journal diameter. Thus, the lower tool cartridge provides two support points to the crankpin diameter or journal diameter.

Fig. 8—Work roller and tooling geometry. Pressure is applied at an angle of 43° to force the work rollers into the corner radii of the fillets being rolled on either the crankpin or main bearing journals of a crankshaft. The 43° angle allows the work rollers to approach the unrolled fillet at an angle less than 45°. The ultimate position of the work rollers at the end of the rolling cycle is 45°, or slightly less due to part tolerances. The squeeze pressure of 624 lb exerted by the lever arms in which the rollers are contained gives a resultant working contact pressure of approximately 385,000 psi.
Fig. 9—DRESSING BAR. This bar precision dresser uses the grinding wheels to grind the crankshaft journals. The bar is constructed of a series of nine diamond-impregnated dressing wheels whose diameter and spacing are the same as the diameter and spacing of the journals of the crankshaft.

Fig. 10—PROJECTING COMPARATOR. This comparator checks main bearing journal spacing and radius contours for both journals and crankpins. The accuracy of the comparator at a magnification of 15 times enables rigid quality control to be maintained over the forms and tangential blending of all radius areas.

of stock so that a full radius, according to process tolerances, could be finish ground. The width of the main bearing journal rough grinding wheels was made 0.020 in. narrower than the width of the finish grinding wheels. This variation in width, along with proper spacing tolerances, assured that the finish grinding operation on the journals would leave ample stock to produce a quality radius.

To grind a precise radius on main bearing journal fillets, Oldsmobile uses a diamond radius dressing bar (Fig. 9). This bar is constructed of a series of nine diamond-impregnated radius form dressing wheels whose diameter and spacing are the same as the diameter and spacing of the journals of the crankshaft. After the periphery of the grinding wheels are finish dressed, the diamond dressing bar is placed in the grinding fixture in the same manner as the crankshaft. The fixture then is run through an automatic cycle similar to that used when grinding crankshaft journals. During this one cycle, all nine radii of the crankshaft journal grinding wheels are precision dressed.

To check the bearing journal spacing and radius contours of both the bearing journals and crankpins, a special comparator was developed (Fig. 10). The accuracy of the comparator enables rigid quality control to be maintained over the forms and tangential blending of all radius areas.

Summary

The introduction of the cold working method for tangentially rolling the fillets of crankshaft radii has provided excellent results in increasing fatigue life. The cold working concept also is being considered for future application to other areas of the crankshaft. For example, a testing program is currently in effect at Oldsmobile to roll the diameters of crankpins and main bearing journals instead of using an abrasive finishing process. Good results from a geometric and finish standpoint have been obtained. On experimental parts processed to date, it has been possible to roll surfaces on crankpin and journal diameters from 60 to 70 RMS down to two to three RMS in ten seconds. The program on cold rolling diameters also is expected to provide further improvements in roundness, surface characteristics, and elimination of barrel or hourglass configurations.