METHOD FOR HARDENING CRANKSHAFT
James O. Woodbridge, Warren, Robert M. Spencer, Youngsville, and Donald D. Dyalmyple, North Warren, Pa., assignors to National Forge Company, Irvine, Pa., a corporation of Delaware
Filed Jun. 6, 1966, Ser. No. 519,899
2 Claims. (Cl. 148—16.6)

The present invention relates to the manufacture of crankshafts and more particularly to an improved method for hardening the main and pin journal surfaces to improve their wear qualities and also hardening the fillet zones located at the ends of the journal bearing surfaces where the latter merge into the web faces of the crankshaft which establish the necessary offset, or crank throws between the main and pin journals.

In the construction and design of crankshafts, it has been found particularly desirable to provide fillets as distinguished from sharp, line transitions at the junctions between the journal bearing surface ends and the web faces in order to increase the fatigue strength of the crankshaft at the ends of the journals where the crankshaft is subject to its most severe stresses during operation and thereby minimize the possibility of fractures and operational crankshaft failure at these locations. To further enhance this strengthening effect at the fillet zones, it has also been conventional to harden the crankshaft in the fillet zones by various surface hardening techniques which will induce favorable residual compressive stresses in the critically stressed areas.

The surfaces of the main and pin journals are, of course, subjected to severe wear conditions especially when the crankshaft is operating under a heavy load and, to retard this wear, it has also long been conventional to harden the journal surfaces by various surface hardening techniques.

This hardening of the journal surfaces and fillet zones has, for example, been carried out by rapid heating of the parts to be hardened and then quenching them. The heating of the parts can be effected by causing very heavy, medium frequency induced, electrical current to circulate near the surface, the current being produced by means of the well known induction process wherein properly configured inductors are fitted about the journal surfaces and fillet zones and current passed through them thus inducing the flow of a secondary or heating current in the areas to be hardened. The crankshaft may or may not be rotated during the induction hardening cycle. When the parts have reached the proper temperature, the current is interrupted and the parts immediately quenched thus completing the hardening technique. However, hardening by this so-called induction technique is not without its disadvantages since the required heating often creates residual stresses in the crankshaft such that after a heating and quenching cycle, the crankshaft will be distorted from its original configuration, especially between the web faces, thus making it necessary to straighten the shaft and thus introducing a new pattern of undesirable tensile stresses at these very critical locations in the shaft where it is subject to its maximum working stresses after being put into service in an engine, or compressor. It is also quite possible that the crankshaft material will lack sufficient ductility during the straightening operation to prevent creation of hairline cracks with the result that the crankshaft will often have to be rejected and scrapped. In addition, severe local tensile stresses can exist in the transition zone between the hardened and unhardened areas which can further be detrimental to the life of the crankshaft, especially if the transition zone is close to the critical fillet area.

Moreover, while induction hardening of the journal surfaces themselves is not too difficult, it is quite difficult to maintain a uniform pattern of hardening in the fillet zones due to the difficulty in configuring the inductors themselves at these zones such that the flow of induced current conforms to the desired uniform hardening pattern in the fillet zones. Straightening after treatment becomes extremely difficult.

Another technique in common use for hardening of the bearing surfaces and fillet zones of crankshafts is that of "nitriding." One common nitriding practice is a process wherein the crankshaft is placed within a sealed bell, or some other suitable furnace enclosure, and the parts of the crankshaft desired to be hardened are exposed to anhydrous ammonia at a temperature of from 950°—1,050° F., for a prolonged period. Dissociation of the ammonia occurs and nitrides are formed in the surface layers of the journal surfaces and fillet zones. The advantage of this type of hardening operation is that, due to the relatively low nitriding temperature and the absence of quenching, the hardening can be carried out with a minimum of deformation tensile stresses in the crankshafts and hence, only minor straightening is necessary after nitriding. In addition, the nitrided case imparts high compressive stresses to the surface layer, because it expands in volume (also giving increased rigidity as well as wear resistance). Since most fatigue failures start from high tensile stresses in the critical fillet zones at the very surface, the "built-in" compression of a nitrided layer reduces the magnitude of the tensile stresses imposed by service loadings, thus extending the fatigue life of the crankshaft.

During nitriding, the crankshaft is preferably supported on end in a completely passive manner and this can be effected by means of the apparatus disclosed in U.S. Patent No. 2,803,449, issued Aug. 20, 1957, in the name of Ralph E. Ludwig. Another advantage of hardening through nitriding is that ideal control over the hardening pattern in the fillet zones can be obtained, since the areas to be left unhardened can be blocked off effectively and economically.

One disadvantage inherent in many nitriding processes is that a considerable length of time is required in order to obtain a practical depth of hardness on the journal surfaces themselves, some processes taking upwards of 100 hours to complete. A second disadvantage of nitriding is that the depth of hardness obtained for the bearing surfaces is less than optimum, and a third disadvantage is that the nitriding process gives rise to formation of a very hard and brittle skin of iron-nitride from 0.0005" to 0.001" thick in the outermost surface layers which is commonly known as "white layer," and which should first be removed by grinding or other known techniques before the crankshaft can be put into use. U.S. Patent No. 3,069,296 describes various methods for removing or reducing "white layer."

Crankshafts whose journal surfaces have been hardened when new can be reconditioned in various manners. With a nitrided shaft, the worn journal bearing surfaces can be ground down until a uniformly diametted unworn
base depth is reached and the journal surfaces can then be built back to their original size by chromium plating. A crankshaft having induction hardened journal surfaces can be ground until a uniformly sized unworn base depth is reached—more flexibility is available here since the induction hardening operation reaches to a greater depth than is possible with nitriding—and the undersized journal surfaces equipped with properly sized bearings. This procedure is especially advantageous if chromium plating facilities are not available for rebuilding the worn surfaces.

Thus, it will be appreciated that a crankshaft whose journal surfaces and fillets have been hardened by induction heating and quenching has certain advantages as well as disadvantages—and this is likewise true as regards hardening by nitriding.

The object of the present invention is to provide a hardening technique for the journal surfaces and fillet zones of crankshafts which enjoys the advantages of both processes without, however, entailing their disadvantages. More specifically, the improved hardening technique includes an initial hardening by nitriding of the journal surfaces and fillet zones of the crankshaft in one and the same nitriding operation until one obtains a depth of hardness in the fillet zones sufficient to achieve a desired increase in the fatigue strength of the crankshaft in the critical fillet zones. The hardened fillets will resist cracking and failure of the crankshaft while under load. Thereafter only the nitrided journal surfaces of the crankshaft are subjected to a further hardening treatment involving a quick re-heating of such surfaces, such as, for example, by induction, followed by quenching so as to not only increase the hardness accomplished through nitriding but also increase the depth of the hardened case on the journal surfaces.

The foregoing as well as other objects and advantages inherent in the invention will become more apparent from the following more detailed description of a specific embodiment thereof and from the accompanying drawings where:

FIG. 1 shows a portion of a crankshaft partly in section and partly in elevation; and

FIG. 2 is a graph in which hardness is plotted against depth for the journal portions of the crankshaft for various zones of crankshafts including the one constituting the inventive concept.

With reference now to the drawings, the crankshaft is indicated generally at 1 and is provided with a plurality of main journals 2 and pin journals 3 which are axially offset from the main journals 2 by web face 4. In the end zones where the main and pin journals merge into the web face 4, the transition is preferably accomplished by machining fillets of a generous radius 5 rather than leave a sharp line at the transition point. As previously explained, such fillets are desirable to increase the fatigue strength of the crankshaft at these most critical zones where the shaft is subjected to its most severe stresses during operation, and where most crankshaft failures have been found to occur.

The crankshaft itself can be made from any conventional nitrider steel now in use for this purpose, a typical steel being of the AISI 4130 or 4140 grade.

In accordance with the improved hardening technique, an initial hardening of the fillet zones and of the main and pin journal surfaces is accomplished by a nitriding operation. This nitriding step can be carried out in a conventional manner, for example, with apparatus of the type described in the above mentioned Ludwig Patent No. 2,803,449 in which the crankshaft is supported on end, to minimize distortion and deformation stresses during the heating cycle. The nitriding is carried out at a temperature of from 950° to 1050° F., and is continued for such time as will establish a nitride-hardened case of a depth sufficient to provide the desired compressive stresses and resulting increase in fatigue strength in the critical fillet zones. The main and pin journal surfaces 2 and 3 are, of course, likewise hardened but these surfaces have at least some "white layer" content at the skin, and are of less than optimum depth at this point of the hardening procedure. A typical depth and pattern of the nitrided parts below the surface of the crankshaft is designated by the dashed lines.

In accordance with the invention, further hardening of the main and pin journals is now accomplished by subjecting only the nitrided portions of the main and pin journals 2 and 3 exclusive of the fillet areas to a subsequent hardening step which involves a quick heating of only the main and pin journal surfaces to a temperature within the austenitizing range for the steel followed by quenching until a temperature is reached such that substantially all of the austenite in the nitrided portions of the journal surfaces is transformed in nitrogen-bearing martensite. The necessary quick-heating of the nitrided main and pin journal surfaces can be accomplished in any suitable manner but induction type heating is probably the most practical since the zone to be heated, i.e., the journal surfaces but not the fillets, is more easily controllable by design of the inductors which are fitted about the journal surfaces.

The second stage of the hardening operation, which has been done, using a frequency of 3,000 cycles/sec., increases the depth of hardness initially effected by nitriding, and a typical depth and pattern of the additional hardening accomplished in the main and pin journals is indicated by the dash-dot lines. It will be understood that the depths of dash-dot lines as well as the dash lines as shown in the drawings are not to scale but have been exaggerated to show clearly on the drawing. Moreover, in addition to an increase in the depth of hardness, the hardness of the steel itself, for example A.I.S.I. 4130, is increased to a value higher than that which is usually obtained by conventional induction hardening technique for this same steel as shown in the comparative graphs of FIG. 2.

In conclusion, it will be appreciated that a two stage hardening technique for crankshafts in accordance with the invention produces a superior crankshaft which will be better able to withstand service stresses and overloads for a longer period of time without failure compared to a standard equivalent induction hardened crankshaft. Moreover, the hardening operation itself of the main and pin journal surfaces and of the fillet zones is more desirable since one is able to reduce, if not eliminate altogether, creation of dangerously high deformation tensile stresses in the critical fillet zones found in induction hardened crankshafts which not only increase the danger of forming surface fissures in these zones but also lead to a reduction of further undesirable stress operation and the creation of further undesirable stress operation in the shaft itself which then necessitates a straightening operation and the creation of further undesirable stress operation in the shaft itself. In addition to the accomplishment of hardened fillet zones with favorable residual compressive stresses to improve the fatigue strength of the shaft at these critical locations where most crankshaft failures occur, the journal surfaces themselves can be hardened to a greater depth and to a higher degree of hardness not heretofore obtainable with use of either nitriding or induction hardening procedures alone. Moreover, the undesirable "white layer" characteristic previously inherent in nitriding operations is actually eliminated in the journal areas as a result of the second hardening operation.
the nitrided portion of said journal to a temperature within the austenitizing range for the steel followed by quenching until a temperature is reached such that substantially all of the austenite in the nitrided portion of said journal is transformed into nitrogen bearing martensite.

2. In the method of hardening the main and pin journals of a steel crankshaft as well as fillet zones established between the ends of said journals and the web faces which offset the main and pin journals, the steps which comprise nitriding said journals and fillet zones in one and the same nitriding operation to obtain an initial hardening of said journals and a final favorable residual compressive stress hardening of said fillet zones thereby to increase the fatigue strength of said fillet zones, and thereafter subjecting only the nitrided journals to a subsequent hardening treatment by rapidly heating only the nitrided portions of said journals to a temperature within the austenitizing range for the steel followed by quenching until a temperature is reached such that substantially all of the austenite in the nitrided portion of said journals is transformed into nitrogen bearing martensite.

References Cited

UNITED STATES PATENTS

<table>
<thead>
<tr>
<th>Patent Number</th>
<th>Date</th>
<th>Inventor</th>
<th>Citation</th>
</tr>
</thead>
<tbody>
<tr>
<td>2,803,469</td>
<td>8/1957</td>
<td>Ludwig</td>
<td>266—5</td>
</tr>
<tr>
<td>3,216,869</td>
<td>11/1965</td>
<td>Koistinen</td>
<td>148—166</td>
</tr>
<tr>
<td>3,257,865</td>
<td>6/1966</td>
<td>Seulen et al.</td>
<td>74—595</td>
</tr>
</tbody>
</table>

CHARLES N. LOVELL, Primary Examiner.