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REVIW ON OPTIMIZATION OF CRANKSHAFT

Sagar Khatri[1] Dipak Kharade[2] Kiran Varpe[3]

[1,2,3,]*T.E.Scholar BVCOERI,Nashik,Pune University*

ABSTRACT

This Study Demonstrates Crankshaft Counterweight Profile Optimization To Achieve Better Dynamic Balancing. Balancing Simulation Was Carried To Predict Initial Unbalance. During Balancing Of Actual Crankshaft, The Position Of Unbalance Is Sometime Shifted Due To Machining Stock Distribution Towards Non-Favorable Direction Resulting In To More Number Of Balancing Holes, Thus Productivity Loss. To Reduce This, Counterweight Profile Optimized. After Balancing, Bending Fatigue Test Carried Out. Crankshaft Exhibited Pre-Mature Failure At Unusual Location. To Determine The Reason Of Failure, Stress Analysis Was Performed Using FEA. Design Enhancement Solution Proposed To Reduced The Stresses And Subsequently Enhance Bending Fatigue Strength.

Keywords-Vehicle Development, Computer Aided Engineering, Design Optimization, Materials, Iron And Steel Materials, Engine Components, Fatigue, Crankshaft Balancing[B2]

I. INTRODUCTION

The crankshaft, sometimes casually abbreviated to crank, is the part of an engine which translates reciprocating linear piston motion into rotation. To convert the reciprocating motion into rotation, the crankshaft has "crank throws" or "crankpins", additional bearing surfaces whose axis is offset from that of the crank, to which the "big ends" of the connecting rods from each cylinder attach.It typically connects to a flywheel, to reduce the pulsation characteristic of the four-stroke cycle, and sometimes a torsional or vibrational damper at the opposite end, to reduce the torsion vibrations often caused along the length of the crankshaft by the cylinders farthest from the output end acting on the torsional elasticity of the metal.Crankshaft is a large component with a complex geometry in the engine, which converts the reciprocating displacement of the piston to a rotary motion with a four link mechanism.Since the crankshaft experiences a large number of load cycles during its service life, fatigue performance and durability of this component has to be considered in the design process. Design developments have always been an important issue in the crankshaft production industry, in order to manufacture a less expensive component with the minimum weight possible and proper fatigue strength and other functional requirements. These improvements result in lighter and smaller engines with better fuel efficiency and higher power output.The crankshaft consists of the shaft parts which revolve in the main bearings, the crankpins to which the big ends of the connecting rod are connected, the crank arms or webs (also called cheeks) which connect the crankpins and the shaft parts. The crankshaft main journals rotate in a set of supporting bearings ("main bearings"), [Fig.1.1] causing the offset rod journals to rotate in a circular path around the main journal centers, the diameter of that path is the engine "stroke": the distance the piston moves up and down in its cylinder. The big ends of the connecting rods ("conrods") contain bearings ("rod bearings") which ride on the offset rod journals.

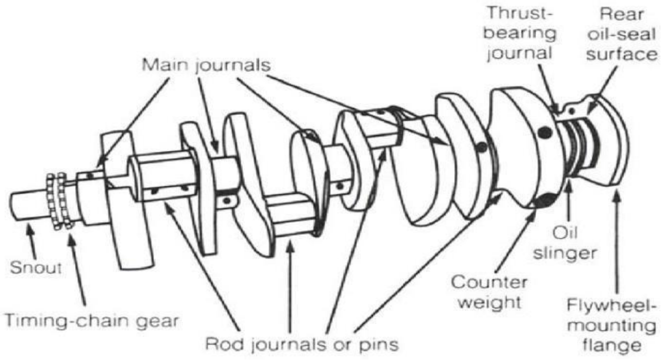


Fig. 1.1Typical Crankshaft with Main Journals that Support the Crankshaft in the Engine Block, Rod Journals is offset from the Crankshaft Centerline

II. HISTORY

Find from the modern turkey and excavation from Germany shows that as early as the 3 rd century A.D. the roman used power transmission via crankshaft. To pump water out of ever increasingly deep mine shafts, one needed efficient lifting machine and here again one turn to the principles of motion of transformation. The crankshaft attached to the wheel acted upon the pump rod to produce and up and down motion, thus causing the water to rise. Design developments have always been an important issue in the crankshaft production industry, in order to manufacture a less expensive component with the minimum weight possible and proper fatigue strength and other functional requirements. These improvements result in lighter and smaller engines with better fuel efficiency and higher power output. Two different crankshafts from similar engines were studied in this research. The finite element analysis was performed in four static steps for each crankshaft. Stresses from these analyses were used for superposition with regards to dynamic load applied to the crankshaft. Further analysis was performed on the forged steel crankshaft in order to optimize the weight and manufacturing cost. Figure 1.1 shows a typical picture of a crankshaft and the nomenclature used to define its different parts.

III. OBJECTIVE

The overall objective of this study was to evaluate and compare the fracture Performance of a crankshaft. In addition, weight and cost reduction opportunities for optimization of crankshaft were also investigated This study was motivated by a need for a study of fracture of crankshafts, which are the most commonly used manufacturing processes for an automotive crankshaft. In addition, it was desired to develop an optimized geometry, material, and manufacturing procedure which will reduce the weight and manufacturing cost due to high volume production of this component. This research was performed on crankshafts from single cylinder engines. However, since the basis of analysis are the same for multi-cylinder engines, the procedures used could be modified and implemented for crankshafts from other types of Engines. Other studies on crankshafts from multi-cylinder engines are typically performed on a portion of the crankshaft consisting of two journal bearings and one crankpin bearing, which is similar to that a single cylinder engine. The only major difference in engines with different number of cylinders is the dynamic analysis of the loads applied to the component

IV. LITERATURE SURVEY

4.1.Review Of Papers

1. The paper entitled "Crankshaft Design and Optimization- A Review", by the authors

Amit Solanki, Ketan Tamboli, M.J.Zinjuwadia, published at „National Conference on Recent Trends in Engineering & Technology", states that the performance of any automobile largely depends on its size and working in dynamic conditions. The design of the crankshaft considers the dynamic loading and the optimization can lead to a shaft diameter satisfying the requirements of automobile specifications with cost and size effectiveness.

2. The paper entitled "Crankshaft Failure and Why It May Happen Again", by the authors D.A. Moore, K.F. Packer, A.J. Jones, and D.M. Carlson published in ASM

International „Practical Failure Analysis", states that fracture initiated in a segregated region near the neutral bending axis of pin and produced a woody fracture plane perpendicular to the direction of imposed piston loading. This woody fracture existed prior to machining and induction hardening. The woody fracture location, orientation, and size are similar in both crankshafts. The large woody fracture region was produced by stresses that acted in a cross planar direction as evidenced by the orientation of secondary cracking. The woody fracture pre-existed final machining and heat treatment, as evidenced by the disruption of tool withdrawal markings in the oil hole on crank. (A similar determination was not possible on crank because the material containing the oil hole and woody fracture intersection was not available.) Regions of segregated material, including MnS inclusions and higher carbon, tempered martensite bands, existed throughout the crankshaft with some segregated areas extending to or near the journal surface. Cracking continued from the edges of the woody fracture plane through the hardened case to the journal surface in service by low cycle fatigue. Fatigue propagation was by combined bending and torsional stresses. The actual level of these stresses as compared to design or expected st ress levels in this engine is unknown. When the fracture reached the bearing interface, spalling and localized seizure caused bearing failure and engine outage. Lubrication conditions appeared nominal as evidenced by bearing, piston, and oil examination.

V. SYSTEM DEVELOPMENTS

5.1 Crankshaft Materials

Crankshafts materials should be readily shaped, machined and heat-treated, and have adequate strength, toughness, hardness, and high fatigue strength. The crankshafts are manufactured from steel either by forging or casting. The main bearing and connecting rod bearing liners are made of Babbitt, a tin and lead alloy. Forged crankshafts are stronger than the cast crankshafts, but are more expensive. Forged crankshafts are made from SAE 1045 or similar type steel. Forging makes a very dense, tough shaft with a grain running parallel to the principal stress direction. Crankshafts are cast in steel, modular iron or malleable le iron. The major advantage of the casting process is that crankshaft material and machining costs are reduced because the crankshaft may be made close to the required shape and size including counterweights. Cast crankshafts can handle loads from all directions as the metal grain structure is uniform and random throughout. Counterweights on cast crankshafts are slightly larger than counterweights on forged crankshafts because the cast metal is less dense and therefore somewhat lighter.

(1) Manganese-molybdenum Steel

This is a relatively cheap forging steel and is used for moderate-duty petrol-engine crankshafts. This alloy has the composition of 0.38% carbon, 1.5% manganese, 0.3% molybdenum, and rest iron. The steel is heat-treated by quenching in oil from a temperature of 1123 K, followed by tempering at 973 K, which produces a surface hardness of about 250 Brunel number. With this surface hardness the shaft is suitable for both tin-aluminum and lead-copper plated bearings.

(2) 1%-Chromium-molybdenum Steel

This forging steel is used for medium-to heavy-duty petrol- and diesel-engine crankshafts. The composition of this alloy is 0.4% carbon, 1.2% chromium, 0.3% molybdenum, and rest iron. The steel is heat-treated by quenching in oil from a temperature of 1123 K and then tempering at 953 K. This produces a surface hardness of about 280 Brinell number. For the use of harder bearings, the journals can be flame or induction surface-hardened to 480 Brinell number. For very heavy duty applications, a nitriding process can produce the surface to 700 diamond pyramid number (DPN). These journal surfaces are suitable for all tinaluminum and bronze plated bearing

(3) 2.5%-Nickel-chromium- molybdenum Steel

This steel is opted for heavy-duty diesel-engine applications. The composition of this alloy is 0.31% carbon, 2.5% nickel, 0.65% chromium, 0.55% molybdenum, and rest iron. The steel is initially heat-treated by quenching in oil from a temperature of 1003 K and then tempered at a suitable temperature not exceeding 933 K. This produces a surface hardness in the region of 300 Brinell number. This steel is slightly more expensive than manganese-molybdenum and chromium- molybdenum steels, but has improved mechanical properties.

(4) 3%-Chromium-molybdenum or 1.5%-Chromium-aluminum- molybdenum Steel

These forged steels are used for diesel-engine crankshafts suitable for bearing of hard high fatigue-strength materials. The alloying compositions are 0.15% carbon, 3% chromium, and 0.5% molybdenum or 0.3% carbon, 1.5% chromium, 1.1% aluminum, and 0.2% molybdenum. Initial heat treatment for both steels is oil quenching and tempering at 1193 K and 883 K or 1163 K and 963 K respectively for the two steel. The shafts are case-hardened by nitriding, so that nitrogen is absorbed into their surface layers. If the nitriding is carried out well in the journal fillets, the fatigue strength of these shafts is increased by at least 30% compared to induction and flame-surface- hardened shafts. The 3%-chromium steel has a relatively tough surface and hardness of 800 to 900 DPN. On the other hand the 1.5%-chromium steel casing tends to be slightly more brittle but has an increased hardness, of the order of 1050 to 1100 DPN.

(5) Nodular Cast Irons

These cast irons are also known as speroidal-graphite irons or ductile irons. These grey cast irons have 3 to 4% carbon and 1.8 to 2.8% silicon, and graphite nodules are dispersed in a pearlite matrix instead of the formation of fake graphite. To achieve this structure about 0.02% residual cerium or 0.05% residual magnesium or even both is added to the melt due to which the sulphur is removed and many small spheroids in the as-cast material are formed.

5.2 Materials and Manufacturing Processes

The major crankshaft material competitors currently used in industry are forged steel, and cast iron. Comparison of the performance of these materials with respect to static, cyclic, and impact loading are of great interest to the automotive industry. A comprehensive comparison of manufacturing processes with respect to mechanical properties, manufacturing aspects, and finished cost for crankshafts has been conducted by Zoroufi and Fatemi (2005).This Section discusses forging and casting processes as the two competing manufacturing processes in crankshaft production industry. Influencing parameters in both processes are detailed. Finally, the forged steel and the cast iron products are compared in terms of material properties and manufacturing processes.Many high performance crankshafts are formed by the forging process, in which a billet of suitable size is heated to the appropriate forging temperature, typically in the range of 1950 - 2250°F, and then successively pounded or pressed into the desired shape by squeezing the billet between pairs of dies under very high pressure. These die sets have the concave negative form of the desired external shape. Complex shapes and / or extreme deformations often require more than one set of dies to accomplish the shaping.

Originally, two-plane V8 cranks were forged in a single plane, then the number two and four main journals were reheated and twisted 90° to move crankpins number two and three into a perpendicular plane. Later developments in forging technology allowed the forging of a 2-plane "non-twist" crank directly.

Fig. 3.1.Two-Plane V8 Crankshaft Raw Forging.

Billet crankshafts are fully machined from a round bar ("billet") of the selected material. This method of manufacture provides extreme flexibility of design and allows rapid alterations to a design in search of optimal performance characteristics. In addition to the fully- machined surfaces, the billet process makes it much easier to locate the counterweights and journal webs exactly where the designer wants them to be. This process involves demanding machining operations, especially with regard to counterweight shaping and undercutting, rifle-drilling main and rod journals, and drilling lubrication passages. The availability of multi-axis, high-speed, high precision CNC machining equipment has made the carved- from-billet method quite cost-effective, and, together with exacting 3D-CAD and FEA design methodologies, has enabled the manufacture of extremely precise crankshafts which often require very little in the way of subsequent massaging for balance purposes.

5.3 Failures Of Crankshaft

5.3.1Failures

1. Thermal cracks
2. Breaking f Journal Bearing.
3. Enlarged Keyway.
4. Cracks in Thrust collar.
5. Second main journal Thermal Crack.
6. Excess run out at 915 main Journal.
7. Fourth crankpin having cracks at both ends.
8. Bearing size is enlarged.

9. Fifth crankpin has dart mark.
10. Z type crack.
11. 8th and 9th main journal excess run out.

5.3.2Causes of Major Failures

1. Viscosity of lubrication oil is too low.
2. If there is fault OSD (Over speed dripper) equipment attach in engine which cause heavy failure in CRANKSHAFT.
3. If the engine speed exceeds the rated RPM of the engine..
4. If the engine is operated at over load.
5. If the Lubricating oil is not changed periodically.
6. If the oil filter is not changed periodically.
7. Improper functioning of Engine monitoring system.
8. Excessive wear of Journal bearing.
9. Irregular maintenance of engine.
10. 10. Inefficient engine Operator.
11. Drivers cannot follow the operator manual.

VI. CRANK SHAFT DESIGN

6.1 Stresses In Crankshaft

The crankpin is like a built in beam with a distributed load along its length that varies with crank position. Each web like a cantilever beam subjected to bending & twisting. Journals would be principally subjected to twisting.

1. Bending causes tensile and compressive stresses.
2. Twisting causes shear stress.
3. Due to shrinkage of the web onto the journals,

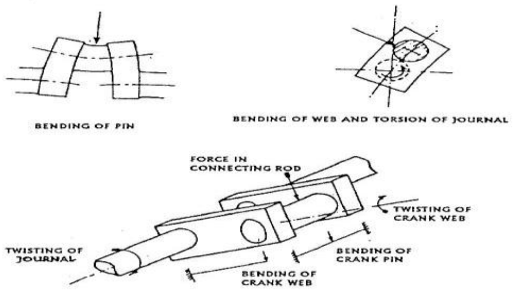


Fig. 4.1Stresses in Crankshaft.

Compressive stresses are set up in journals & tensile hoop stresses in the webs.

The equality constraint is geometry limitations or fixed dimensions. And finally the design variables are upper and lower limit for size and geometry, material alternatives, and manufacturing processes.

Size optimization is an optimization approach, where the parameters do not change the overall shape of the component and only the size is modified. Geometrical

properties parameters such as thickness, diameter, and area are used as design variables in size optimization. There are other optimization methods such as Shape Optimization and Topological Optimization, which change the appearance of the geometrical domain.

VII. .OPTIMIZATION OF CRANKSHAFTS

7.1 Optimization

The optimization study performed on this component was not the typical mathematical optimization process. There are different functions and limitations in the mathematical optimization, which are all defined as a set of variables. The main objective function is minimizing the weight, maximum stress at critical locations, and manufacturing cost. This function is subject to inequality constraints, equality constraints, and side constraints having the design variables as a tool for any optimization process. The bounded constraint in this component is maximum allowable stress of the material. The equality constraint is geometry limitations or fixed dimensions. And finally the design variables are upper and lower limit for size and geometry, material alternatives, and manufacturing processes.Size optimization is an optimization approach, where the parameters do not change the overall shape of the component and only the size is modified. Geometrical properties parameters such as thickness, diameter, and area are used as design variables in size optimization. There are other optimization methods such as Shape Optimization and Topological Optimization, which change the appearance of the geometrical domain.

7.2 Objective Function

Objective function is defined as the parameters that are attempted to be optimized. In this study the weight, manufacturing cost and fatigue performance of the component were the main objectives. Optimization attempt was to reduce the weight and manufacturing cost, while improving the fatigue performance and maintaining the bending stiffness within permissible limits.

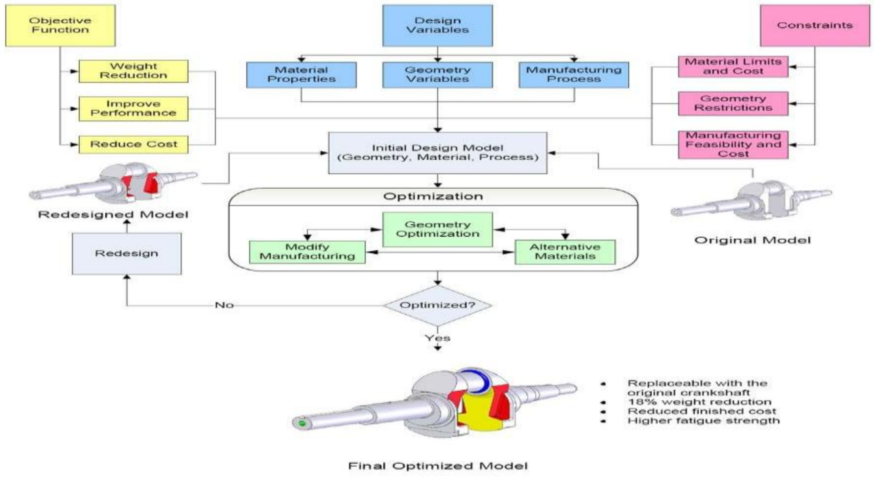


Figure 5.1 General flow chart of forged steel crankshaft optimization procedure.

7.3 Design Variables

Parameters that could be changed during the optimization process are design variables. Considering the functions of the crankshaft and its constraints, the following design variables were considered in the optimization study:

Stage I:

- Thickness of crank web
- Geometry of crank web
- Increasing inner hole diameters and depths
- Geometry changes on the outer part of crankpin bearing

Stage II: Variables in stage I and

- Changes in fillet radii
- Change of connecting rod bearing length
- Change in the main bearing diameters

Manufacturing process and material alternatives are other design variables that were considered in this study. Since automotive crankshafts are mostly manufactured from microalloyed steels, this was considered as the alternative material. Microalloyed steels have the main advantage of eliminating the heat treatment step in the manufacturing process, which will reduce the cost of the final crankshaft. Other manufacturing aspects that are common in manufacturing of crankshafts including inducing compressive residual stress at the fillets were investigated to improve the fatigue performance of the component. This improvement would allow additional changes in the geometry in order to reduce the weight of the final optimized crankshaft.

Case 1: Increasing the depth of the drilled hole at the back of the crankshaft

Since the dynamic balance is one of the main concerns in the optimization of this component as the first step it was tried to remove material symmetric to the central axis, which would not disturb the dynamic balance of the crankshaft stress results for the critical location for different optimization cases, where value of one on the vertical axis of the fatigue stands for the original crankshaft (73 MPa for mean stress, 188 MPa for stress range, and 3.72 kg for weight). The slight change (1%) in stress range for Case 1 is a result of selection of the critical node, because each model is meshed separately and the node numbers and position slightly change. Therefore, each time a node is selected, a variation could be seen in the results.

Case 2: Increasing the hole diameter of the crankpin oil hole

Another optimization step which does not require any complicated changes in the geometry is increasing the hole diameter of the crankpin hole. Increasing the inner diameter of this hole will result in decreasing the moment inertia of the cross section. Therefore, in order to not increase the stress level at the fillet area, the fillet radius has to be increased. Increasing the fillet radius does not affect the connecting rod geometry since the current connecting rod has enough clearance. Applying these changes to the crankshaft causes the center of mass to move toward the counter weights. In order to balance the modified crankshaft, material has to be removed from the counter weight.

Case 3: Redesigning the geometry of the crankpin

Any weight reduction made on the crankpin geometry would result in material removal from the counter weights for dynamic balance of the crankshaft. Therefore, the next option considered for weight reduction was to redesign the crankpin geometry and remove material from this section. Material was cut from the outer geometry of the crankpin. . In this case, the stress range increased by 10%, .The increase of stress was a result of higher stress concentration factor, which not only depends on the two diameters of the shafts and the fillet radius, but also depends on the thickness of the crank web, which was reduced in this case.

Case 4: Rectangular material removal from the center of the crank web symmetricto the central axis

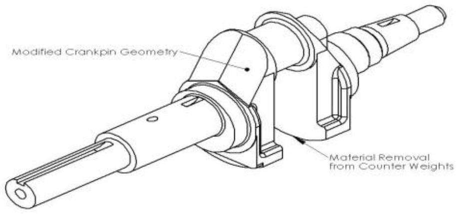
The weight reduction option for this case. Material removal in the shape of rectangular was considered since the dynamic balance of the crankshaft would not be disturbed and further dynamic redesign of the counter weights were not necessary. The rectangle could be cut out from one side to the end of the other side, as far as the center of the rectangle remains centered to the central axis of the main bearings. The height of the rectangle is limited to the geometry of the crankpin bearing.

Case 5: Semi-circle material removal from the center of the crank web symmetric to the central axis

This step is a result of improvement of the previous step. Since the rectangular section depth is limited to the oil hole from the upper part, the middle section could be cut out more. Removing more material from the middle section of the crank web symmetric to the central axis resulted in cutting half circle from each part and reducing the weight more than 5%, in comparison with the original crankshaft.

Case 6: Modification of the crank web design

Redesigning the crank web and removing material is the next optimization case that was applied to the crankshaft. Changing the design was with consideration of the manufacturing process. The final designed geometry should be feasible for the manufacturing process, which requires not having negative slopes. The crank web was modified such that no changes in the counter weights would be necessary.



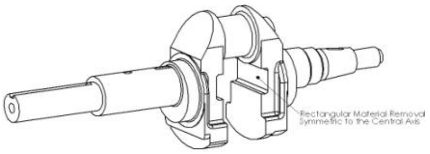
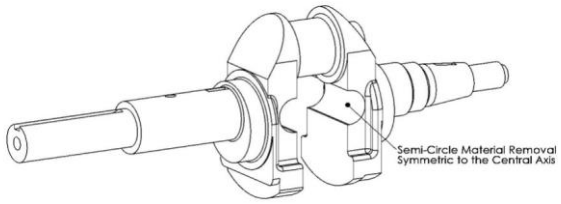


Figure 5.2 Case 3 Figure 5.3 Case 4



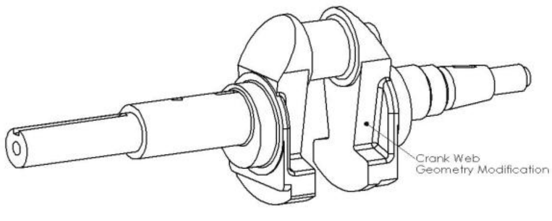


Figure 5.4 Case 5 Figure 5.5 Case 6

7.4 Modification to Manufacturing Process

As the next step for the optimization study it is tried to modify the production steps in order to reduce the cost or improve the performance of the current crankshaft. Further improvement of the performance could result in more geometry changes and weight reduction. The optimization in this section was investigated by considering adding compressive residual stress to the fillet area of the crankpin. Inducing compressive residual stress increases the fatigue strength of the crankshaft. Therefore, adding compressive residual stress on the fillet area of the current crankshaft increases its fatigue strength by 40% to 80% based on the material properties, crankshaft geometry, and applied rolling force.

Since the nitriding process is time consuming in comparison with other heat treatment processes, it was not considered as a modification to manufacturing process to increase the performance of the crankshaft.

The effects of different surface hardening treatments such as quenching and tempering, ion-nitriding or fillet rolling on the fatigue properties were investigated in Pichard et al. (1993) research. Table 5.5 summarizes these effects. The fatigue bending moment for microalloyed 35MV7 steel without surface treatment was 1990 N.m. As could be seen in this table, the fatigue strength increases by 87% and 125% by fillet

Table 5.1 Fatigue experiment results on specimens from competitor crankshaft materials (Pichard et al., 1993).

MATERIAL	STATE	SURFACE HARDENING TREATMENT	BENDING MOMENT (N.m)
Ductile iron	As cast	Without	± 1500
Alloyed ductile iron	Q. + Temp.	Ion nitriding : 4 h	± 2230
Ductile iron	As cast	Fillet rolling. P (°) : 8000 N	± 2935
1042 steel	Q. + Temp.	Ion nitriding : 4 h	± 3480
35 MV7 steel	Cont. Cooled	Fillet rolling. P(°) : 9000 N	± 3715
35 MV7 steel	Cont.Cooled	Fillet rolling. P(°): 12000 N	± 4472
35 MV7 steel	Cont.Cooled	Ion nitriding : 4 h	± 4660
32 CDV13 steel	Q. + Temp.	Ion nitriding : 7 h	± 5170

(°) P = Pressure

7.5 Modification Using Alternatives Materials

One of the most common alternatives for the forged steel material is microalloyed steel. Pichard et al. (1993) performed a study on a microalloyed (MA) steel with titanium addition specially adapted for the production of forged crankshafts and which does not require any post-forging treatment. The use of MA steel enables elimination of any further heat treatment, resulting in shorter manufacturing process and consequently an increase in the forged crankshaft productivity. The metallurgical choice of this MA steel for crankshaft applications was based on the 35MV7 steel grade, with a typical composition of 0.35C, 1.8Mn, 0.25Si, 0.12V, and micro-addition of Ti. Based on the results of their research, 35MV7 control-cooled microalloyed steel shows similar tensile and rotating bending fatigue behavior as AISI 4142 quenched and tempered steel. In addition, the machinability of the microalloyed steel can be improved by about 40% in turning and about 160% in drilling (Pichard et al. 1993).

The effect of using different material with the same surface treatments are summarized in Table 5.1. As could be seen in this table, the quenched and tempered 1042 steel with short nitriding treatment has 56% higher fatigue strength than the quenched and tempered alloyed ductile iron with the same nitriding time. The quenched and tempered 32CDV13 steel with 7 hour nitriding time has the highest fatigue strength, which is about 49% higher than quenched and tempered 1042 steel with shorter nitriding time. Cost reduction of 13% is obtained for the final crankshaft by replacing the traditional AISI 4142 steel with 35MV7 control-cooled microalloyed steel. This includes 10% savings on the unfinished piece, 15% saving on mechanical operations and 15% saving on ion nitriding treatment (Pichard et al. 1993).A comparison between the material properties used in the current crankshaft, AISI 1045 steel, and microalloyed steel 35MV7 indicates similar yield strengths, 12% higher tensile strength, and higher fatigue strength (by 21%) at 10^6 cycles for the microalloyed steel, as summarized in Table 5.2. Further study on the cost of final product is discussed in the cost analysis section.

7.6 Cost Analysis

Cost analysis is based on geometry changes and weight, modification in manufacturing process and the use of alternative material. The optimized geometry requires redesign and remanufacturing the forging dies used. The geometry parameters that influence machining and the final cost of the component include the increase of drilling process, because the drilled holes at the back of the crankshaft and the crankpin are redesigned to have larger diameters, and the bore at the back is modified to have more depth than the original bore.Adding residual stress by fillet rolling process is a parameter in the manufacturing process that will add to the cost of the finished component. Although microalloy grade steel, as of March 2007, is $0.028/lb more expensive than hot-rolled steel bar, the heat treatment cost savings, which are at least $0.15/lb, are large enough to offset this difference (Wicklund, 2007). Apart from the heat treatment costs, the use of microalloyed steel also results in savings in machining costs stemming from enhanced production rates and longer tool life (Nallicheri et al. 1991). In addition, microalloyed steel has 5% to 10% better machinability than quenched and tempered steel (Wicklund, 2007). Considering these factors, along with the reduced material cost due to the 18% weight reduction for Stage I and 26% for Stage II, indicates significant reduction in the total cost of the forged steel crankshaft. It should, however be mentioned that Stage II requires higher cost angular contact ball bearing and additional analysis is needed for this stage, which may result in additional changes in the crankshaft, connecting rod, and piston assembly. Figure 5.36 shows the modified manufacturing process for the optimized crankshaft considering aforementioned changes.

Table 5.2 Typical mechanical and fatigue properties of Ti-added controlled-cooled 35MV7 steel (Pichard et al., 1993) and AISI 1045 steel (Williams and Fatemi, 2007).

Steel	Heat Treatment	Ultimate Strength (MPa)	Yield Strength (MPa)	Fatigue Strength (MPa)	Percent Elongation (%)	Percent Reduction in Area (%)
AISI 1045	Q + T	827	625	395	54	58
35MV7	Cont. Cooled	925	630	478	15	50

VIII.CONCLUSIONS

In this semminar we design the crank shaft And the next step of this study, geometryand manufacturing cost optimization was performed on the forged steel crankshaft. In the first stage of geometry optimization local geometry changes at different locations on the crankshaft were considered. Final optimized geometry from the first stage, which is replaceable in the engine without any change to the engine block and the connecting rod, is a result of combining local geometry optimization potentials considering manufacturing feasibility and cost.

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