

4 Versus 8 Counterweights for an I4 Gasoline Engine Crankshaft – Measurements of Vibration and Bearing Wear

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ABSTRACT

The authors have published SAE paper 2008-01-0088 on the analytical comparison between 4 and 8 counterweight crankshafts for an I4 gasoline engine. This paper showed that for a particular design of a 4 counterweight crankshaft, the differences in bearing force and oil film thickness were very small and the only major difference in terms of bearing shaft tilt angle occurred at mains 2 and 4 (increase of ~20% compared with 8 counterweight version). The 4 counterweight crankshaft has a significant mass advantage as it was 1.42kg lighter than the 8 counterweight crankshaft.

This new paper addresses the testing performed to validate the analysis results in bearing durability by subjecting the engine to a mixture of high speed and general durability cycles. A comparison was made on the bearing conditions after running a total of 100 hours through prescribed durability cycles on a gasoline engine with both 4 and 8 counterweight crankshafts. Visual bearings inspection and bearing wear measurements were performed on all main bearings and torsional displacement measurements were also made. The torsional vibration measurements were used to correlate the 3D dynamics model of the crankshaft. In addition, the effects of 4 and 8 counterweight crankshafts on the cylinder block and bedplate vibration were also investigated.

This paper concludes that by using the crankshaft counterweight design strategy proposed in 2008-01-

0088, it is possible to achieve acceptable bearing durability of a 4 counterweight crankshaft for an I4 gasoline engine while also gaining a significantly lower mass than the 8 counterweight version of the crankshaft for the same engine.

INTRODUCTION

To control the mass of the engine, it is necessary to question the design of each component. Significant mass reduction can also result in cost reductions, particularly in a world of rising material costs.

Most I4 gasoline engines larger than 2000cc have a design configuration where all crankshaft webs have counterweights in order to reduce the maximum and average bearing force, thus increasing the fatigue life of the main bearings. For significant mass reduction, particularly in engines smaller than 2000cc, some crankshafts have only 4 counterweights instead of 8 on an I4 gasoline engine.

An analytical comparison by the authors of this paper suggested that by using just 4 counterweights instead of 8, the known criteria for a good design of the main bearings of an I4 gasoline engine can be met, while achieving a significant amount of mass reduction (about 9% for the crankshaft design in this paper) [1].

Recent studies show that the engine noise level is not significantly increased by reducing the counterweight mass on a crankshaft [2 and 3]. One study also states that there is almost no increase at all in the engine noise

level when the crankshaft balancing rate is reduced from 100% to 82% [4].

This paper is a continuation of SAE 2008-01-088 and focuses on the effects of the 4 and 8 counterweight crankshafts on the cylinder block and bedplate vibration, crank train torsional vibration and the main bearing wear undergoing engine durability testing recorded on the same I4 gasoline engine. For the engine durability testing, the engine is subjected to a 50-hour general durability cycle and 50-hour rated speed cycle for each crankshaft build.

The objective of this paper is to make an experimental comparison between a 4 and 8 counterweight crankshaft for the same engine.

CRANKSHAFT DESIGN PHILOSOPHY

The design philosophy on the number of counterweights on the crankshaft revolves around the bay balance factor and the packaging constraint clearance limit between the counterweight radius and piston at bottom dead center position (BDC), and the connecting rod locus clearance limit to the crankcase wall.

The crankshaft counterweight size for each variant was selected to give a calculated minimum oil film thickness of 0.5 μm at all five main bearings at 6600 rev/min with no load [1]. As a consequence, the required bay balance factor for the 4 counterweight version was lower (57.6%) than that of the 8 counterweight version (80.8%). This was possible because at main bearing no. 3, the oil film thickness was dominated by the size of the counterweights on webs 4 and 5. For the 4 counterweight version, the counterweights on webs 1, 4, 5 and 8 had larger radii (77mm) than the counterweights on all webs of the 8 counterweight version (74mm). However, the removal of the counterweights on webs 2, 3, 6 and 7 resulted in a reduction of total crankshaft mass of 1.42kg (~9% of mass reduction). Figures 1 and 2 show the 8 and 4 counterweight crankshaft designs respectively.



Figure 1: Crankshaft with 8 counterweights



Figure 2: Crankshaft with 4 counterweights

ENGINE SPECIFICATIONS AND TESTING CONDITIONS

The specification for the IL4 gasoline engine and testing conditions for this investigation are listed in Table 1.

Specifications and conditions	Value
Bore (mm)	86.0
Stroke (mm)	94.6
Firing order	1-3-4-2
Rod length (mm)	145.7
Piston assembly mass (kg)	0.46
Rod assembly mass (kg)	0.56
Main bearing diameter (mm)	55.0
Lubricant grade	5W40
Oil supply pressure at main gallery (bar)	3.8 to 4.0
Oil supply temperature at main gallery (°C)	90 to 110

Table 1: Engine specifications and testing conditions

ENGINE TESTING OVERVIEW

Vibration and durability tests were performed to investigate the effects of 4 and 8 counterweight crankshafts. The engine tests reveal the effects of the choice of counterweight strategy on:

- Cylinder block and bedplate vibration
- Crank train torsional vibration
- Main bearing wear

CYLINDER BLOCK AND BEDPLATE VIBRATION TESTING

For the cylinder block and bedplate vibration testing, three points on the left and right sides of the cylinder block, and three corresponding points on the bedplate were measured. These points were located close to the crankshaft centreline.

Steady state measurements were made from 1000 rev/min to 6500 rev/min in increments of 500 rev/min. The measurements were made at 0%, 25%, 50%, 75%, and 100% load. Vibration data were acquired and processed using LMS Test. Lab version 8. The vibration results were averaged from all accelerometers on both sides of the engine. The results are shown as weighted vibration velocity summed between 500 Hz

and 5 kHz, as this is considered to be the closest correlation to the radiated noise from the engine.

CRANK TRAIN TORSIONAL VIBRATION TESTING

Torsional vibration analysis and testing were conducted to compare the torsional vibration of both crankshaft designs. Analysis was performed using Ricardo ENGDYN and correlated with engine test data.

A series of torsional vibration measurements were taken to determine the differences in torsional vibration between the 4 and 8 counterweight crankshaft designs. Data were taken using inductive probes targeted at the crank nose and flywheel.

Speed sweep measurements were made from 1000 rev/min to 6000 rev/min at 100% load. The data were acquired using LMS Test. Lab version 8. The results were processed in Matlab R2006b using codes developed by Ricardo.

ENGINE DURABILITY TESTING

Based on the analysis results in SAE paper 2008-01-0088, a test procedure was devised aimed at comparing the effects on main bearings using 4 and 8 counterweight crankshafts. In each test, the engine is subjected to two durability cycles in which the cumulative hours came up to 100 hours.

The engine durability test was initially performed on the 4 counterweight crankshaft and followed by the 8 counterweight version. The first cycle involved running the engine at engine rated speed WOT for 50 hours. The procedure was then followed by a general durability cycle derived from the analysis results conducted earlier as shown in Table 2.

Stage	Engine speed [rev/min]	Load [%]	Torque [Nm]	Duration (s)
1	1000	0	20	315
2	2000	50	132.5	180
3	2500	100	265	300
4	4000	100	265	300
5	5500	100	243	1020
6	6000	100	220	300
7	6200	100	197	300
8	6200	10	50	300
9	4000	20	50	180
10	2000	50	132.5	180
			Total	3600*

Table 2: General Durability Cycle

*The cycle is repeated until the engine completed 50 hours.

The engine with the 4 counterweight crankshaft was stripped after completion of 100 hours and main bearings conditions visually and quantitatively evaluated.

The aforementioned procedure was then repeated for the 8 counterweight crankshaft.

TEST DATA ANALYSIS

EFFECTS OF THE 4 AND 8 COUNTERWEIGHT CRANKSHAFTS ON CYLINDER BLOCK AND BEDPLATE VIBRATION

The following figures 3 and 4 show 500 Hz - 5 kHz sum across an engine operating map.

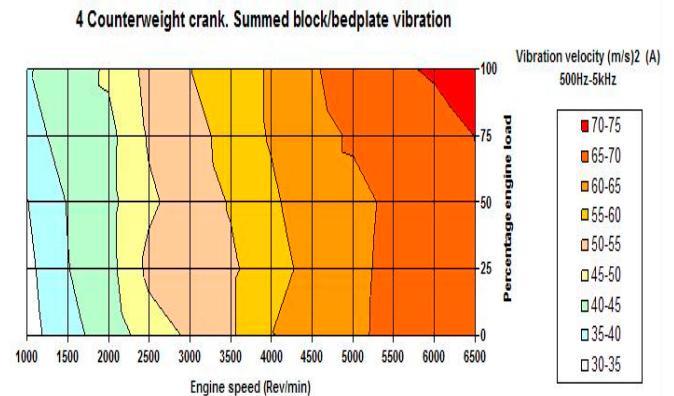


Figure 3: Summed block/bedplate vibration for 4 counterweight crankshaft.

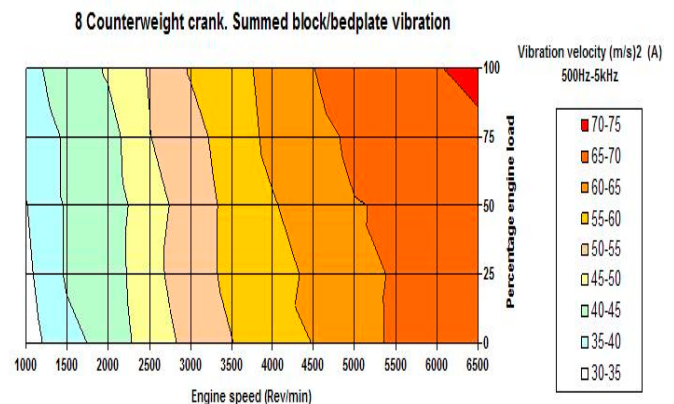


Figure 4: Summed block/bedplate vibration for 8 counterweight crankshaft.

The summed block/bedplate vibration recorded no significant difference between the 4 and 8 counterweight crankshafts.

The subsequent figures 5 to 8 depict the differences in the crankcase and bedplate vibration levels for the 4 and 8 counterweight crankshafts at 2500 rev/min, 25% load and 3500 rev/min, 25% load. The data show the surface velocity 'A' weighted for the 4 and 8 counterweight crankshaft builds.