Fatigue Analysis of DOHC Engine Rocker Arm & Characterization using Taguchi Method

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Abstract— Cam shaft design has advanced in leaps and bounds over last three decades but overhead valve engines with centrally located camshafts still use lifters and push rod and rocker arms as a means of opening and closing the intake and exhaust valves in fuel injection pumps. Advancement in materials used in construction of rocker arm for reducing the noise, weight and higher strength for efficient operation is going on throughout the globe since long. The usual materials used for such purpose are Steel, Tungsten, Aluminum, and Forged steel to Stainless steel, aluminum alloys and composites. The success to investigate the possibility creating a light weight rocker arm that could provide a higher fatigue life, friction reducing fulcrum using needle bearings and a roller tip for reduced friction between the rocker and the valve stem but still be less expensive than steel lies in the development of composite rocker arms. Lighter mass at the valve is also allowed for increased speed while strength of the material caters to durability.

Key words: DOHC Engine, Rocker Arm, Taguchi Method

I. Introduction

Advancement in materials used in construction of rocker arm for reducing the noise, weight and higher strength for efficient operation is going on throughout the globe since long. The usual materials used for such purpose are Steel, Tungsten, Aluminum, and Forged steel to Stainless steel, aluminum alloys and composites. The success to investigate the possibility creating a light weight rocker arm that could provide a higher fatigue life, friction reducing fulcrum using needle bearings and a roller tip for reduced friction between the rocker and the valve stem but still be less expensive than steel lies in the development of composite rocker arms. Lighter mass at the valve is also allowed for increased speed while strength of the material caters to durability.

The rocker arm usually operates at 40-500 C and the maximum pressure is exerted by the gas. Therefore in this investigation it has been thought proper to analyze a rocker arm of structural steel, aluminum alloy and composite. Static structural fatigue analysis may be carried out to determine the stresses and make a comparison between steel and composites to predict the failure modes.

II. Working of Rocker Arm

Rocker arm is an important part of the valve train in fuel injection system providing not only the means of actuating the valves through a fulcrum utilizing the lifter and the push rod but also provide a means of multiplying the lift ratio. Cam shaft design has advanced in leaps and bounds over last three decades but overhead valve engines with centrally located camshafts still use lifters and push rod and rocker arms as a means of opening and closing the intake and exhaust valves in fuel injection pumps.

A. *Rocker Arm Ratio*

A rocker arm is simply a mechanically advantaged lever that translates camshaft data into valve actuation. The mechanical advantage is defined by a rocker's ratio.

The standard small-block Chevy (SBC) uses a 1.5:1 ratio rocker arm. In other words, the rocker-arm tip (output) moves 1.5 times the displacement of its pushrod socket (input), or camshaft-lobe lift. The 1.5:1-ratio rocker arm translates 0.350 inches of camshaft-lobe lift into 0.525 inch of valve lift (0.350 inch x 1.5 = 0.525 inch). By increasing the rocker-arm ratio, it's possible to increase valve lift without ever touching the camshaft. A 1.6:1-ratio rocker arm translates the same 0.350 inch of camshaft-lobe lift into 0.560 inch of valve lift (0.350 inch x 1.6 = 0.560 inch). This is a lift increase of about 6.7 percent. Valve lift can typically be increased as much as 10 percent by increasing rocker ratio.

Since rocker arms are used to control both the intake and exhaust valves, swapping high-ratio rocker arms onto an engine increases both the intake-air command and the exhaust-scavenging potential. Generally speaking, a bump in rocker-arm ratio results in a noticeable performance gain. The almighty General knows this; GM swapped in a set of high-ratio 1.6 (up from the LT1's 1.5) rockers on the LT4 and later specified the LS7 ratio at a healthy 1.8 (up from the LS2's 1.7).

B. *Rocker Arm- Form & Function*

Rocker arm with a sintered hardened pad that rides on the camshaft lobe with an encapsulated hydraulic lifter built inside on the other end to open the valve. Rocker arms simply aren't what they used to be. With lighter, stronger materials, as well as computer-aided design, and lifter bore. Take the Chrysler Neon 2.0L DOHC engine, in fig. shown below for example. The exhaust rocker arm is designed like a wishbone. The rocker arm has a roller bearing on one end, riding on a single camshaft lobe, while the other end, two encapsulated hydraulic lifters rides on two exhaust valves. It's topped off with a plastic cap to pivot on the valve tip what a challenge it is to make this part: you have a metal roller bearing pinned to an aluminium body with a metal hydraulic lifter bored inside the aluminium arm. The hydraulic lifter unit's clearance-to-bore is so minute that the inside has to be thermally deburred. Otherwise the lifter may not leak down properly. Reducing the weight of the rockers will reduce the reciprocating mass of the valve train. But experts say reducing the weight on the valve side of the rockers usually benefits the engine's rpm more than changing the pushrod side. The offset of the rocker arm creates a leverage effect that uses the rocker lift ratio to multiply the weight savings on the valve side. For example, take a small block Chevy with a stock rocker arm ratio of 1.5:1. Every gram of weight removed on the valve side is worth 150 percent of any weight savings on the pushrod side.

So eliminating six grams of weight from the valve side of this valve train with lighter components such as valve spring retainers or valves has the same net effect as cutting 4 grams of weight from the lifters or pushrods. Reducing valve train weight means you can achieve the same rpm with less spring pressure, less friction, and less wear. Of course, innovation doesn't end at weight reduction. Relocating the roller tip forward or backward, maximum rocker arm geometry is achieved. Changing the rocker arm ratio increases valve lift for more power. But changing the rocker arm pivot point can also reduce friction and the rate at which the valves open and close, adding horsepower with little or no loss in low rpm torque, idle quality or vacuum. By opening and closing the valves at a faster rate, the engine flows more air for the same number of degrees of valve duration. High lift rocker arms also reduce the amount of lifter travel needed to open the valves, which reduces friction and the inertia of the lifters and pushrods that must be overcome by the valve springs to close the valves. On the other hand, increasing the rocker ratio also increases the effort required to open the valves because of the leverage effect. The higher the rocker arm ratio, the greater the force the camshaft, lifters and pushrods have to exert to push the valves open. But when the valves close, the increased leverage of the rocker arms works the other way making it easier for the springs to shut the valves and push the rocker arms, pushrods and lifters back to their rest positions. On small block Chevy engines, the stock stud-mounted rocker arms are supposed to be self-centering and self-aligning.

Fig. 1: DOHC Engine

They can't handle valve train misalignment very well. If the rocker arm twists, it may bend the pushrod and/or allow the tip of the rocker arm to walk off the side the valve tip. If that happens, the rocker may push down on the retainer instead of the valve, causing the locks to pop out and the valve to disappear down the guide, destroying the engines. There's a lot of talk these days about shaft-mounted rocker arms, and while they may seem to be a throwback to the days before the first stud-mounted stamped steel rocker arms appeared on small block Chevy V8s in 1955 they have been engineered for today's engines. One of the features that made the SB Chevy such a performer was its lightweight, high revving valve train. But that was a time when maximum engine speeds were in the 6,500 to 7,000 rpm range, not 8,500 to 9,000 rpm or higher, and most engines were running single springs, not double or triple springs.

Shaft mounted rockers offer a number of advantages today. The rigid shaft holds the rockers in perfect alignment, eliminating the need for separate pushrod guide plates while also limiting valve train deflection. At high rpm, pushrods and rocker arm studs can flex quite a bit, and the more they deflect the more it hurts valve lift, duration and valve control. This costs horsepower which can be seen on a dyno. So the more rigid the valve train, the less the valve flutter at high rpm.

Shaft mounted rocker arms also provide extra strength and support, eliminating the need for a separate stud girdle. Aluminium stud girdles are often necessary to reinforce the valve train when a high lift cam (or rockers) and stiff springs are used. The girdle clamps around the studs and ties them together to reduce stud flex and the risk of breakage. But the girdle also makes it harder to adjust the valves. Shaft mounted rocker arms, with adjusters on the arms, not the studs, are easily accessible. Mounting the rocker arms on a rigid shaft also eliminates the "jack-hammering" effect that occurs with stud-mounted rockers. Every time the valve opens and closes, the change in valve lash that occurs with a solid lifter cam causes a stud-mounted rocker arm to slide up and down on its stud. This hammering effect can pull a pressed-in stud out of the cylinder head, and may cause fatigue failure in a screw-in stud or the rocker arm.

III. Assumptions of the Taguchi Method

The additive assumption implies that the individual or main effects of the independent variables on performance parameter are separable. Under this assumption, the effect of each factor can be linear, quadratic or of higher order, but the model assumes that there exists no cross product effects (interactions) among the individual factors. That means the effect of independent variable 1 on performance parameter does not depend on the different level settings of any other independent variables and vice versa. If at any time, this assumption is violated, then the additivity of the main effects does not hold, and the variables interact.

A. Designing an Experiment

The design of an experiment involves the following steps

- Selection of independent variables
- Selection of number of level settings for each independent variable
- Selection of orthogonal array
- Assigning the independent variables to each column
- Conducting the experiments
- Analyzing the data

IV. Static Structural Analysis

A static analysis calculates the effects of steady loading conditions on a structure, while ignoring inertia and damping effects, such as those caused by time-varying loads. A static analysis can, however, include steady inertia loads (such as gravity and rotational velocity), and time-varying loads that can be approximated as static equivalent loads (such as the static equivalent wind and seismic loads commonly defined in many building codes.

V. FATIGUE ANALYSIS

Fatigue is the progressive, localized, permanent structural change that occurs in materials subjected to fluctuating stresses and strains that may result in cracks or fracture after a sufficient number of fluctuations. Fatigue fractures are caused by the simultaneous action of cyclic stress, tensile stress and plastic strain. If any one of these three is not present, fatigue cracking will not initiate and propagate. A fatigue crack is started by cyclic stress, whereas crack propagation is produced by tensile stress. In general, this phenomenon has attracted attention because progressively more and more is demanded from machine parts in term of speeds of operation and loads to be sustained.

The process of fatigue failure consists of three stages

1) Stage I - Initial fatigue damage leading to crack nucleation.
2) Stage II - Progressive cyclic growth of a crack (crack propagation) until the remaining Uncracked cross section of a part becomes too weak to sustain the loads imposed.
3) Stage III - Final, sudden fracture of the remaining cross section.

Fatigue analysis enables designers to estimate the fatigue life of new products, such as automobiles, airplanes, heavy equipment, electric motors and electronic components. Analysis provides data about fatigue life, crack propagation and strength, which you can use to make informed choices to ensure product integrity and optimize fatigue life-preventing premature product failure in the field.

In the past, fatigue theory was complicated and daunting, and mostly experts used fatigue analysis successfully. Modern simulation tools, such as ANSYS Design life, make this critical job easier. They encapsulate a wide range of capabilities-methods for low –cycle and high-cycle fatigue and differing types of loading histories-that together provide a comprehensive fatigue analysis process.

You can capture the powerful analysis process in a workflow, which makes simulation easier since it requires less effort to set up and run problems. You can think of the workflows as a “wizard” that reduces the amount of data the user has to provide. This technology Tip demonstrates how to create a custom fatigue analysis workflow along with how to save it for future use together with the default workflows ANSYS

VI. ANOVA ANALYSIS

The results from the experiments conducted using ANSYS 14.0 are taken and used in the determination of optimal combinations of input parameters i.e., material as well as arm ratio for each of the output parameters using Taguchi methods.

Minitab 17 is used in for Taguchi experimental design and the L9 orthogonal array is used. The plots for signal to noise ratio for tool life, total deformation, and factor of safety and vonmisses stresses are plotted.

VII. FATIGUE LIFE

The graph shows the signal to noise ratio for minimum life .Since the minimum life has to be maximum the larger the better criteria is considered. It can be concluded that the material at level 1 and Arm Ratio at level 1 i.e. structural steel with 1:1 Arm Ratio will give maximum life than the remaining combinations.

VIII. SAFETY FACTOR

The above graph shows the signal to noise ratio for maximum factor safety .Since the maximum factor safety has to be maximum the larger the better criteria is considered.

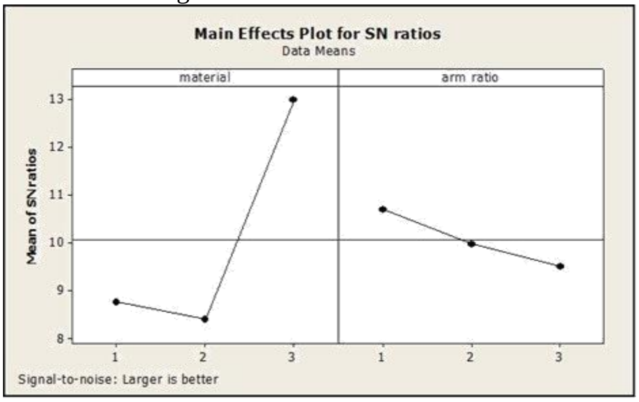

Fig. 2:

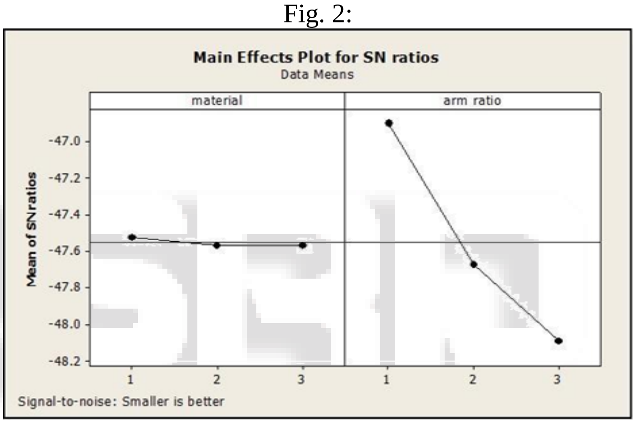

Fig. 3:

The above graph shows the signal to noise ratio for equivalent stresses .Since the equivalent stresses has to be minimum the smaller the better criteria is considered.

It can be concluded that the material at level 3 and Arm Ratio at level 3 i.e. Aluminium composite with 1:1.3 Arm Ratio will give minimum than the remaining combinations.

IX. TOTAL DEFORMATION

The above graph shows the signal to noise ratio for minimum deformation .Since the minimum deformation has to be minimum the smaller the better criteria is considered.

It can be concluded that the material at level 2 and Arm Ratio at level 3 i.e. Aluminium alloy with 1:1.3 Arm Ratio will give minimum deformation than the remaining combinations.

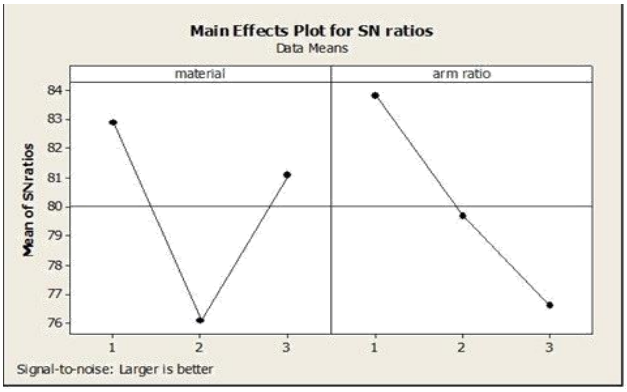

Fig. 4:

X. CONCLUSIONS

It can be concluded that the fatigue life of the rocker arm is influenced by the arm ratio and material of rocker arm with it is made .Using taguchi method the optimal combination for maximum fatigue life is for rocker made with structural steel and arm ratio 1:1.

- The total deformation is minimum in the case of material Tungsten and arm ratio 1:1.3.
- The stresses are minimum when Al and arm ratio 1:1.3 are adopted.
- The optimal combination for factor of safety is Al composite with an arm ratio of 1:1.

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