CHAPTER 6

DISCUSSION

6.1 OVERVIEW

An experimental study of the tribological behavior of small four-stroke engines during hot tests has been presented. The information obtained has been truly enlightening and would lead towards developing a no-oil hot test procedure that can be implemented on the production line of small four-stroke engine manufacturing plants. It can also possibly aid in establishing a standard for evaluating the efficacy of lubricant pre-treatments to be used for no-oil hot tests of small 4-stroke engines. However, it is also important to evaluate and analyze the different approaches that have been taken, in light of the situation that existed or the hurdles that had to be overcome.

6.2 COMPARISON OF TEST SET-UPS

The design of the test set-up, the loading mechanism and the test procedure played a vital role in the outcome of this study. In an unprecedented move, a lawnmower was actually used to mount the engines on and conduct tests. The conditions for doing so were dealt with in section 3.1.

The loading mechanism differed greatly from the actual one used on the assembly line. While a top loaded test procedure (discussed in section 4.2 B) was employed in the manufacturing plant, the laboratory approach used a bottom loading mechanism. The difference in the top and the botton loading mechanisms might cause different stresses/magnitude of stresses to act on the interfaces. Furthermore, the engines on which tests were conducted here at Virginia Tech had *actually* gone through the hot tests, before being subjected to the laboratory tests. Perhaps, this might have had made the tribological interfaces better able to accommodate a fluid film. Therefore, the procedure that was developed had to impose at least the same degree of severity on the engine as the conditions existing during the actual hot tests. As such, the test procedure lasted for 60 seconds, which was far higher than the average hot test time in the manufacturing plant.

Section 4.2 B also mentions that the hot-tests on the production line consisted of two testing cycles. An unloaded cycle (idling) followed by a loaded one where the load is applied by a belt going around the flywheel bowl. In the laboratory tests, however, the test procedure was a loaded 60-second, WOT (Wide Open Throttle) one.

The outcome of the first phase of tests showed scuffing / seizure more often at the connecting rod - crank bearing. This convinced the author that this was the critical interface. However, the shop floor personnel at Tecumseh's plant showed more concern for the condition of the upper main bearing, during phase 2. During this second phase, lubricants that were slightly suspect in phase 1 fared extremely well. The outcome of the third phase of tests (on the minimum bearing clearance engines), where three engines seized at the connecting rod - crank bearing and another three showed scuffing at this juncture, prove that under increased severity of the conditions, there was a higher chance for failure at this particular interface than at others.

In retrospect, the procedure developed for conducting lab tests had brought about failure of the engine at this critical interface (connecting rod - crank bearing), with the same given lubricants, during the first phase itself. As such, it is safe to say that phase 3 actually justifies and proves that the severity of the conditions imposed by the developed procedure is higher than that imposed by the setup on the shop floor, <u>for typical engines</u> and may have matched the conditions for conducting no-oil hot tests on minimum bearing clearance engines on the factory setup.

6.3 IMPORTANT FACTORS IN HOT TESTS

1. A critical factor that could influence the eventual outcome of this study is the fact that no tests have been conducted on horizontal shaft engines. The horizontal shaft engines form a considerable percentage of the engines manufactured and are an integral part of the repertoire of small engine manufacturers. Such 4-stroke engines are lubricated by a process called “splash lubrication”,

which differs from the lubrication method in vertical shaft 4-stroke engines. The difference in the lubrication mechanisms might result in a different amount of lubricant reaching the critical interfaces, thus causing differences in heat dissipation, thermal stresses etc. An important question that comes up is whether the results that have been achieved on the vertical shaft engines can be considered to hold good for the horizontal ones as well.

It is therefore of utmost importance to marshal information about the failure of horizontal shaft engines vis-à-vis vertical ones during hot tests and during normal operation. The author believes that it is inappropriate to extrapolate data obtained thus far to include horizontal engines.

2. The pin-on-disk tests that were conducted on the T-11 pin-on-disk machine eventually determined the lubricant that was used in the final phase of engine tests. Pin-on-disk tests were conducted at different loads and at two temperatures (ambient and 100 C).

   These tests were conducted at the same time as the penultimate phase of tests. The lubricants had to pass through the minimum bearing clearance engine tests, before they could be used on a large scale, on the assembly line. Minimum bearing clearances imply that lesser amount of lubricant can be held at the interface and that surface temperatures would be higher due to frictional heating. As such, lubricants that had exhibited superior anti-wear performance at 100°C on the pin-on-disk tests were selected to act either as the lubricant or a component of the lubricant at the critical interface in phase 4.

At this time, it is imperative to answer whether a correlation can be made between the pin-on-disk and engine tests. Information about the forces acting on the connecting rod - crank bearing was supplied by Tecumseh (Figure 6.1). The figure shows the forces acting on the connecting rod – crank bearing at different crank angles for different engine speeds. It is apparent that the forces act at and around a crank angle of 0° (in this figure), which in reality refers to the time when spark ignition takes place in the cylinder i.e. as the piston reaches the TDC on the compression stroke.

Also, the lubricants that gave a superlative performance in phase 4 had exhibited superior anti-wear and anti-friction attributes (on the pin-on-disk machine) over the corresponding one used in phase 3. These facts once again go to show that such indications led to the selection of the best available lubricant for test # 8 (the first minimum bearing clearance test in phase 4). It is noteworthy that the ends (results of phase 4) have justified the means.

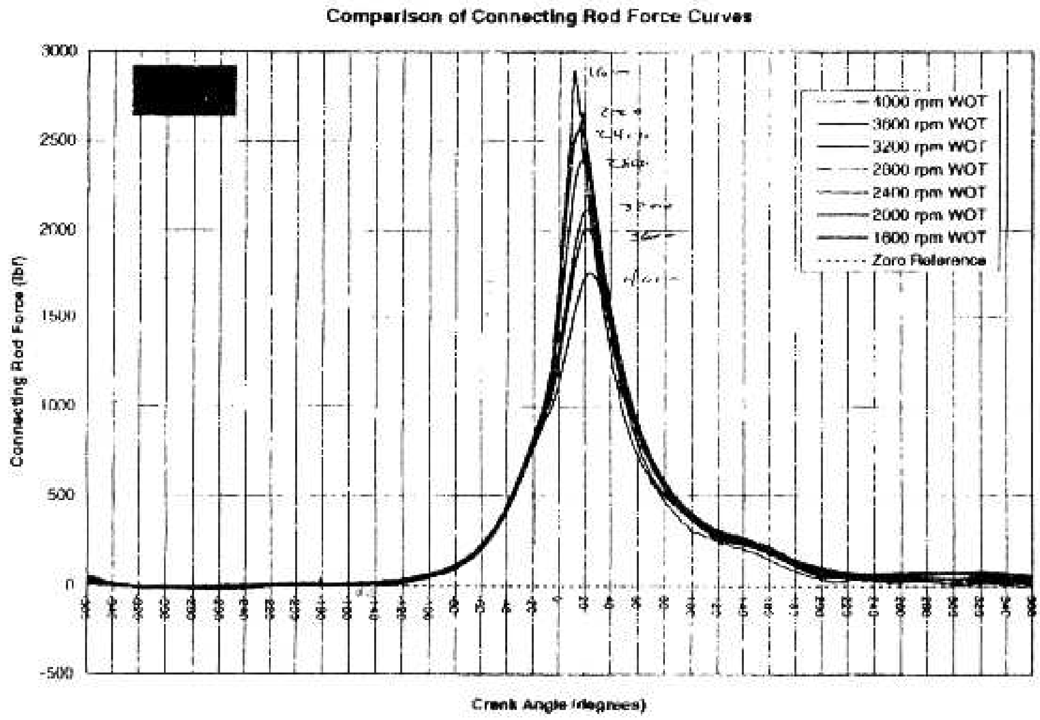

Figure 6.1: Forces acting on the Connecting Rod - Crank Bearing

3. The T-11 Pin-on-disk machine was built to the specifications of Dr. Furey and the first machine of the T 11 series to be built is the one currently being used in the tribology lab of Virginia Tech. Initial trial tests that were carried out on the T-11 led to modifications of the original disk holder and the chamber, as the disk holder could hold only a limited amount of lubricant.

The tests described in Chapter 5 were conducted after these changes were made. Though all tests were conducted at a speed of 0.25 m/s, a distinct deviation from the mean speed was observed on several occasions. There have been instances when the data acquisition stalled and the test continued for more than the time specified. Moreover, though there was considerable wear of the disk, as measured by the stylus profilometer, no wear data was ever given by the displacement transducer. This led the author to believe that the displacement transducer was not sensitive enough to pick up the wear at the interface.

4. Approximately 2 ml of various lubricants was used on the pin-on-disk tests. This lubricant was poured onto the disk in the disk holder, which also acts as a container. The design of this machine caused the lubricant to be subjected to centrifugal forces caused by the rotation of the disk holder. This resulted in most of the lubricant being flung onto the walls of the disk holder and away from the pin-disk interface. This aspect could have serious repercussions such as the inability to model most situations wherein the lubricant put into the disk holder has to exist at the pin-disk interface and not be rendered useless by being flung onto the walls.

5. Tribopolymerization is brought about by the use of minor concentrations of selected compounds capable of forming polymeric films *in situ*. Ipso facto, this work is not covered by that definition, as monomers that were earlier used as additives at 1% and lower have now been used as the major component of the lubricant or as

the lubricant itself (100%). The concept of tribopolymerization could still be valid for pure monomers in liquid or vapor phase i.e. when the pure monomer forms the lubricant, but this work represents an end use of the explorative work of this concept.

Also, no analysis of the deposits (SEM photographs, FTIRM) were carried out to investigate the existence of polymeric films on the interfaces pretreated with the monomers.

6. Photographs of the engine components were taken to complement notes on the condition of the same at different stages of the test i.e. before the test, after the test (before cleaning the components with the solvent) and after the test (after cleaning). Though these photographs were not vital, they have proved indispensable by acting as an archival system and as a means for comparison at a later date.

7. The engines that were tested here at Virginia tech were actually shipped by Tecumseh Engine Products Company in New Holstein, Wisconsin. As mentioned in section 6.2, these engines had already gone through the hot-tests on the assembly line. The question that needs to be answered is the relevance of such tests on engines on which running-in had already begun. The test procedure and setup

were designed to impose more severe conditions on the engine, to overcome this drawback and the results prove that this purpose has been achieved. The disassembly of the first few engines showed that about 60 - 90 ml of the lubricant was left behind in the crankcase and piston cylinder region. Pretreatment on different interfaces was observed but was not vivid. However, disassembly of the final batch of three engines showed a striking, white, viscous, grease like material that had been used to pre-coat the three bearings on the crank shaft.

6.4 SUMMARY

The effect of these issues and suggestions to overcome certain shortcomings are dealt with in the succeeding chapters. The results of each and every engine test were discussed in Chapter 4 itself, along with a discussion of the factors that led to the modification/selection of a particular lubricant formulation. As such, these issues are not broached here to avoid redundancy.