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MONTHLY PROGRESS REPORT

WEAR MECHANISM AND WEAR PREVENTION IN COAL-FUELED DIESEL ENGINES

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INTRODUCTION

Cylinder bore and ring wear in a coal-fueled diesel engine is due to contamination of the ring-liner interface by unburned coal, partial combustion products of the coal, and the noncombustible ash contained within the coal. These contaminants can contribute to the wear through direct interference between the moving parts leading to abrasive wear, or indirectly through disruption of the formation of the boundary layer leading to retarded formation of the hydrodynamic mode of lubrication. The magnitude of the wear depends on the concentration of the particles in the film, the form of the particles (i.e., unburned coal, soot, or ash), the properties of the particles, including the particle-size distribution and the hardness of the particles, and the size of the asperities in the surfaces of the rings and liner.

Solution of the wear problem in coal-fueled diesel engines must include concepts that:

- Maximize the combustion efficiency
- Minimize the contact of the unburned coal with the cylinder liner
- Prevent inclusion of the ash particles in the lubricant film
- Prevent contamination of the lubricant in the crankcase.

The ultimate scope of the problems associated with implementing these requirements depends heavily on determining the mechanism of wear in coal-fueled engines and the contributions of the various possible lubricant contaminants introduced with the use of coal fuels.

OBJECTIVES

The overall objective of this program is to develop the engine and lubricant system design approach that has the highest probability for commercial acceptance. Several specific objectives can also be identified. These objectives include:

- Definition of the dominant wear mechanisms prevailing in coal-fueled diesel engines.
- Definition of the specific effect of each coal-related lube oil contaminant.
- Determination of the potential of traditional engine lubrication design approaches to either solve or mitigate the effects of the coal related lube oil contaminants.
- Evaluation of several different engine design approaches aimed specifically at preventing lube oil contamination or preventing damage due to lube oil contamination.

- Presentation of the engine/lubricant system design determined to have the most potential.

APPROACH

The approach which is being followed in this project is one in which the wear mechanism is examined in two different bench apparatuses. These devices provide much more controlled wear environments than an actual engine, while simulating the ring-liner interface in an actual engine. The two apparatuses, a Cameron-Plint Machine and an Engine Friction and Wear Rig, will be used to determine the effects of the composition and the concentrations of lube oil contaminants on the wear occurring at the interface of a piston ring and cylinder liner. The contaminants will include raw coal, cleaned coal, ash, and combustion products from coal. The goal is to define lubrication solutions to the ring and liner wear problem. In addition, novel engine designs will be examined in a effort to select a design approach which will both reduce the wear problem and be practical to implement in a commercial coal-fueled engine.

PROGRESS THIS PERIOD

Following discussions with the project monitor some decisions have been made concerning the overall work plan, and the priorities for future work on this project. Modified "WORK PLAN" and "LABOR PLAN" forms (DOE forms F1332.4 and F1332.7) were submitted which reflect increased emphasis on Task III, the study of traditional approaches to wear prevention. Work on Task II (Novel Design Concepts) has been delayed to the next fiscal year, and funds have been reapportioned from Task II and other phases of the project to allow for more effort in Task III.

Work on Task III has progressed in the following areas.

- Literature searches on the chemical structure of coal ash, and on the effects of abrasive wear in lubricated surfaces have been continued.
- Formulation of a detailed test matrix is being considered and preparations are being made for the necessary machining on cylinder wear specimens.
- Information is being gathered on oil additives which might be considered in this study.

Literature Searches

The previous progress report outlined some of the details that have been found and conclusions that have been reached so far in each literature search. In the search of coal ash chemical structure, several minerals typically found in coal ash have been identified, of which quartz, alumina, pyrite, and the calcium compounds are the major wear-causing constituents. In the investigations of abrasive wear in lubricated surfaces, papers have been found exhibiting the

sensitivity of wear processes to surface roughness, and the presence of grooves in the surface. The papers indicate that proper design of the surface characteristics can significantly reduce wear.

Having established the general background in each area, the focus of continued literature review will be towards more specific items which directly relate to the wear test investigations. For example, coal ash studies will continue towards further identifying the type of wear caused by each mineral constituent. Ideally, one could then identify the effects of individual minerals in the Cameron-Plint wear tests. Further means of identifying the minerals (using X-ray diffraction techniques for example) in the contaminants used in this study will be investigated as well. In the area of abrasive wear in lubricated surfaces, the emphasis will be on identifying those studies which used similar wearing mechanisms, and/or observed similar wear characteristics to those observed with the Cameron-Plint tests used here. The information could be used to further refine the surface preparation techniques that will be used in the test matrix, or it could be directly compared to the Cameron-Plint results.

Refinement of Test Matrix and Preparation of Wear Specimens

A test matrix was proposed in the previous report outlining tests with various surface finishes, cross-hatch angles and groove configurations. Since it is not feasible to do all possible combinations of all test conditions, some compromises have been considered which would significantly reduce the required number of tests. The revised test conditions and compromises are listed below.

- Surface finishes of approximately 5, 20, and 60 micro-inch will be considered.
- Cross-hatch angles of 0 (circumferential marks only), 30, 60, and 90 (longitudinal marks only) degrees will be used. (The 0 and 90 degree angles will be obtained using grinding processes while the 30 and 60 degree angles will be honed.)
- Tests with the 5 micro-inch surface finish will be performed at only one cross-hatch angle. (Since the 5 micro-inch condition is a highly polished mirror finish, it is unlikely that cross-hatch orientation will make any difference in the wear characteristics.)
- Test specimens with circumferential grooves at two different spacings will be considered.
- Specimens with longitudinal grooves (with the same geometry and spacing as the circumferential grooves listed above) will be tested.
- At least four different oil additives or additive combinations will be tested.

- Tests with the grooved specimens and with the oil additives will be performed using standard surface finish conditions only (20 micro-inch, 30 degree crosshatch angle).
- All of the tests will be performed using the baseline oil alone, and then the baseline oil mixed with 10% Kentucky Splint ash.

Assuming that each test condition will have to be repeated once for verification, the above matrix could be accomplished with 68 four-hour Cameron-Plint tests. This can be reasonably accomplished within the constraints of this project, and still allows for some extra testing if appropriate. The extra testing might include combinations of those conditions most favorable to wear prevention which are not included in the matrix above. There might also be extra testing with carbon-black, or some of the other contaminants on a few selected cases.

Work is progressing towards identifying the machining processes necessary to prepare wear specimens to the surface specifications described above. A honing machine has been located which can provide the 5 to 60 micro-inch finishes with the 30 and 60 degree cross-hatch angles, and a reciprocating grinder has been located to provide the longitudinal (90 degree) orientation. Grinding circumferential marks is more difficult, especially when extremely fine surface finish is required, but since the minimum surface finish requirement has relaxed from 5 to 20 micro-inch, it is felt that this is attainable as well. Machine processes are available which can cut a groove of 0.5 mm width (representing approximately 10X the largest diameter particles seen in these contaminants) without much difficulty.

Investigation of Oil Additives

So far, the investigation of oil additives has been a general review of the literature and the overall categories of additives available. The goal is to reach a decision concerning the most appropriate additives to be used in this study, which will probably come from the following classifications.

- Dispersants, which generally adsorb onto particles, coat the surfaces, and keep them from agglomerating and/or settling out of the liquid, might be useful in keeping the large coal particles and agglomerates out of the wear zone.
- Viscosity enhancers or improvers can generally be used to change the viscosity of the oil, or maintain it under high-temperature conditions. Since viscosity directly influences the hydrodynamic flow conditions, and the formation of the hydrodynamic film, these additives might have a significant effect on wear.

- Extreme pressure additives used to form an adherent film on surfaces where boundary lubrication is necessary might significantly reduce wear, especially at the ring reversal points.

WORK PLANNED FOR NEXT PERIOD

It is anticipated that work will continue in all three of the areas discussed above. Work on the literature surveys will continue towards identifying the specific effects of coal ash minerals on wear, and towards studying the effects of wear specimen surface conditions in similar experiments. Final decisions will be made on the wear test matrix, and the necessary cylinders will be ordered in preparation for machining. Finally, investigations will continue into the most appropriate additives to be used in this project. After surveying the literature and establishing the necessary background information, it is anticipated that oil additive manufacturers will be consulted for a more detailed and thorough analysis of the options available.

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