EUROPEAN CONCERTED ACTION
ON
"Triboscience and Tribotechnology:
Superior friction and wear control in engines and transmissions**"**

COST 532

1. INFORMATION (SUMMARY) SHEET FOR A PROPOSAL

1.1 Title of project

Low-friction engines

Co-ordinator:

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1.2 Information on participating members

1.2.1 Participant 1:

1.2.1.1 Full name of the applicant

VTT Technical Research Centre of Finland

1.2.1.2 Scientist responsible for the project

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1.2.1.3 Proposed effort in man/years per annum of graduates, scientists and technicians.

1.3 man/years per annum.

1.2.1.4 Total cost of project

149 000 EUR per annum, 447 000 EUR in total.

Funding required for project per annum

134 000 EUR per annum, 402 000 EUR in total.

1.2.2 Participant 2:

1.2.2.1 Full name of the applicant

Helsinki University of Technology

1.2.2.2 Scientist responsible for the project

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1.2.2.3 Proposed effort in man/years per annum of graduates, scientists and technicians.

2.15 man/years per annum.

1.2.2.4 Total cost of project

167 000 EUR per annum, 501 000 EUR in total.

Funding required for project per annum

167 000 EUR per annum, 501 000 EUR in total.

1.2.3 Participant 3

1.2.3.1 Full name of the applicant

University of Central Lancashire.

1.2.3.2 Scientist responsible for the project

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1.2.4 Participant 4

1.2.4.1 Full name of the applicant

Volvo Technological Development Corporation

1.2.4.2 Scientist responsible for the project

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1.2.5 Participant 5

1.2.5.1 Full name of the applicant

Wärtsilä Oyj.

1.2.5.2 Scientist responsible for the project

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1.3 Probable duration of project.

The planned duration of the project is 3 years.

1.4 Date at which it is desired that work should begin.

1 April 2003.

1.5 International co-operation with other Signatory States of the Memorandum of Understanding

The project consortium is currently carrying out negotiations with certain European engine component suppliers. The project consortium is looking forward to suggestions that could initiate further project co-operation with additional partners and/or sub-contractors from other Signatory States.

2. ABSTRACT

The proposed project aims at investigating and supporting the development of tribological concepts for friction reduction in internal combustion engines and other applications operating under similarly demanding tribological conditions. The concepts will consist of various combinations of tribomaterials and coatings, micro and macro geometry, and lubricant formulations.

In terms of internal combustion engines, friction reduction with an effect of improving the mechanical efficiency of the engine by approximately one percent unit is the target. As the friction losses of an internal combustion engine mainly occur at the piston assembly and the crankshaft bearings, the research efforts will be concentrated onto these components.

The experimental work is conducted using tribological test equipment and test engines. Basic friction measurements will employ a piston ring tribometer, a journal bearing test rig with dynamical loading, a test engine equipped for piston measurements, and a test engine for fuel consumption measurements. In parallel with the friction reducing effect of the new concepts, their effect on the operational reliability will be studied, and their effect on the exhaust emissions will be determined using a specific test engine with an emission particle analyser.

The experimental results of the project will be analysed on one hand with regard to engine tribology and on the other hand with regard to more common tribological applications, for which purposes results of particular interest will be analysed using commonly accepted tribological rules and formulae and published in peer-reviewed scientific publications. Emphasis will be made to lubricant/surface interactions. International collaboration is forecasted.

3. INFORMATION EXPECTED IN EACH PROPOSAL

3.1 Aim of the study

The aim of the proposed project is to investigate the major sources for frictional losses in internal combustion engines, to quantify the energy losses and describe the wear phenomena taking place due to the frictional work, and to propose improvements in the technical solutions in order to reduce friction. In order to give the largest benefits of the study, the engine sub-systems chosen for the study will comprise the piston-ring-cylinder system, and the crankshaft and conrod bearings.

The project will be based on the experimental and theoretical analysis of different tribological concepts comprising tribomaterials and coatings, micro and macro geometry, and lubricant formulations. The evaluation of the tribological concepts will be conducted with the purpose of serving present production engines and prospected engines with increased power density, as well as general tribological applications operating under demanding conditions. For serving the latter purpose, results of particular interest will be analysed using commonly accepted tribological rules and formulae and published in peer-reviewed scientific publications. The comprehension of the tribotest results will be supported by surface analyses.

With regard to improvements in the understanding of engine tribology, the experimental investigations and computer simulations on the pistons, piston rings and cylinder liner surfaces are due to significantly increase the insights into the friction, wear and lubrication regimes of the reciprocating system. Similarly, the research on crankshaft and connecting rod bearings is due to

increase the knowledge in friction, oil film thickness, oil film pressure and orbit curves of the engine bearings.

The fired engine tests under normal and demanding conditions of increased cylinder pressure will serve as references for the effect of the friction reducing concepts and the operational reliability arising hereof. The engine tests will furthermore give information on the exhaust emissions related to the different tribological concepts studied.

3.2 Background to the study

About 10-20 % of the indicated power of internal combustion engines is lost due to mechanical factors. The mechanical efficiency, *i.e.* the ratio of the brake power to the indicated power, of internal combustion engines usually varies between 0.4 and 0.9. The frictional losses at the sub-mechanisms of an internal combustion engine are responsible for a significant proportion of the mechanical power losses of the engine. Friction losses arise mainly at the pistons, piston rings, bearings and the valve mechanism. Almost 50 % of the losses are related to the piston assembly and about 25 % to the bearings. Reduction in the losses and improvement of the fuel efficiency can be done to some extent by using low viscosity oils and new friction modifiers. The pressure-viscosity coefficient of the lubricant is an important factor, at least in diesel engine oils. With high quality base oils the viscosity does not increase as much as with lower quality base oils in, for example, piston ring/cylinder liner contacts.

The main mission of the piston ring pack is to keep the gas pressure on the combustion chamber side and the lubricating oil on the crankcase side of the piston. Works by several authors have shown that the piston rings largely operate under starved lubrication conditions at the top and bottom dead centres, and that hydrodynamic lubrication is active in the mid-stroke region. Due to the locally poor lubrication conditions, the pistons and piston rings account for the major part of the friction and power loss in internal combustion engines, the proportion depending on the engine type and the operating conditions of the engine. The complete lubrication analysis of the piston skirt is complicated, and the piston ring pack may be the most complex tribological system in an engine.

For increasing the knowledge in the tribological conditions of the piston assembly, complementary research on the tribological parameters of the contact between piston/piston rings and cylinder is hereby proposed. In order to fully benefit from the tribological measurements of the piston assembly in a firing engine, which are very difficult and challenging, the measurement methods will be developed and evaluated. As to support the comprehensive understanding of the tribological conditions at the pistons, realistic model experiments with reciprocating motion at high frequencies will be carried out using a newly developed piston ring tribometer. To complete the analysis of the piston/ring/cylinder contacts, computer simulations need to be carried out.

The crankshaft bearings are highly loaded components of extremely high importance for the reliability of the engine, and probably the most thoroughly studied tribological components of the internal combustion engine. Crankshaft main bearings and connecting rod big end bearings operate under similar, dynamically loaded conditions. Hence, the designs of crankshaft and connecting rod big end bearings are generally quite similar, and currently often based on sophisticated multi-layer journal bearing designs, largely based on lead-bronze or aluminium alloy bearing materials.

In a lubricated contact, friction and wear depend on the lubricant, the mating materials and the surface quality. In internal combustion engines, the lubrication of bearings is usually elastohydrodynamic and the oil film is very thin. Improvements in the surface quality of the bearings and reductions in the lubrication rate lead to more thin oil films. In practice, the oil films are never perfect, hence unlubricated contacts with high local friction and wear tend to appear in internal combustion engines. This problem requires new and innovative material solutions.

The performance of engine bearings is commonly evaluated through the calculation of a number of parameters, namely the minimum oil film thickness, the maximum oil film pressure, the through cycle bearing power loss and the oil flow. The parameters can be determined by computer simulation, with sufficient accuracy for reliable engine design. The development of bearing prediction techniques based on the elastohydrodynamic lubrication theory, which takes into consideration the deflection of the surfaces under the high oil pressure, has made available a powerful tool, and difficult physical phenomena such as cavitation in fluid films and contacts of rough surfaces can be predicted by computer simulations. For being practically relevant, the results of measurements of bearing oil film thickness and oil temperatures using a firing engine can be used as starting and verification values for the bearing simulation programs. In addition to engine tests, crankshaft bearings have been tested in rig tests.

In the proposed project, crankshaft bearings will be studied in a bearing test rig developed for this particular purpose. Connecting rod bearings will be included in the study if found necessary during the project. In the test rig the test bearings can be dynamically loaded, and lubrication parameters can be recorded at a high frequency. The results of the tests with the bearing rig tests will be compared with the results of computer simulations of the journal bearings.

Engine lubricants consist of base oil and additives. In the past, additive technology has been the major component of change in oil formulations. In the future, the role of the base oil is growing. An expressed need for extended oil drain intervals, better fuel economy, reduced emissions etc. will lead to use of high category base oils. For many cases, the oil drainage can be optimised by applying oil diagnostics in terms of particle contents and the chemical state of the oil. By optimisation of the oil and the sealing, particulate emissions from a lubricant can be lowered significantly. The continuously tightening engine emission limits set the focus of interest to particle, nitrogen oxide, carbon dioxide and hydrocarbon emissions. Environmental reasons furthermore make it necessary to study the properties of new basic oils that affect engine friction and fuel consumption. There is a common need on the market for solutions comprising an oil with high thermal resistance and a long oil drain interval. The lubrication oils used in the tests were chosen with emphasis on their relevance regarding modern standards. The oils used in the experimental work include both new oils and used ones. Practical advantages of the results of the project can be obtained by considering the new solutions that increase the total efficiency and operation reliability and decrease the emissions from the engines.

The engine tests of the proposed project, with the aim of determining the mechanical efficiency of the engines with respect to different tribological concepts and assessing the exhaust emissions following from the tribological modifications, will add knowledge in the overall influence of various modifications on the engines.

3.3 Practical value of the project

3.3.1 Practical problems which the study will address

Practical problems within the above topics that are brought up by the industrial participants of the project will be given particular emphasis during the work.

The project will bring more insight into the piston ring and skirt friction, and the bearing friction and lubrication conditions. The results of experimental studies will be compared with the results of computer simulations and with the results of similar investigations found in the literature, and thus to complement previously available information. The miniature piston ring tests will provide detailed information on the variations in friction and lubrication conditions at different locations of the stroke. The fired engine tests and particularly the test facilities incorporating an increased power density will be useful for providing novel information on the tribological behaviour of the piston.

During the proposed project, experimental research on the effect of increased power density will be conducted. The experimental results of the project will show the influence of an increased power density on the tribological performance of the sub-systems of the engine, and address the main problems arising thereof, as well as suggest solutions to meet the tightening demands.

The results of the fuel consumption and exhaust emission measurements will show the environmental effects of the new tribological concepts, in terms of the conservation of the energy resources and in terms of exhaust emissions related to the new tribological concepts.

3.3.2 The economic benefit expected from the research

Increases in the power efficiency will directly lead to reductions in fuel consumption, which means lower costs per energy unit produced and simultaneously lower carbon dioxide emissions. An improvement in the mechanical efficiency rate of an internal combustion engine by at least a percent unit, by adopting optimised tribological solutions, is forecasted. Wear reduction, which will be studied as part of the project, has a direct reducing effect on the maintenance costs related to the operation of an engine.

It is furthermore expected that the results of more common tribological nature will find their way into various tribological applications operating under demanding conditions. The economic impact of this will be seen both in energy savings and in reduced maintenance costs.

3.4 Plan of research

3.4.1 Description of the approach applied in the study

Participant 1

The work at VTT, the Technical Research Centre of Finland, is carried out at two departments, namely VTT Industrial Systems and VTT Processes.

At VTT Industrial Systems, which acts as the project co-ordinator, the focussed research on piston ring tribology will be based on miniature tests in the piston ring tribometer, which has been developed for this particular purpose. Ordinary pin-on-disc tests will be included in the study as additional tests whenever found appropriate. In the piston ring tribometer equipment, a piston ring sample reciprocates on a stationary cylinder liner sample, and the tangential force is recorded from the piston ring sample, by using a moving force transducer. The piston ring offers

reciprocating frequencies up to 50 Hz, temperatures up to 230 °C, normal loads up to 100 N and a stroke length of 40 mm. The technology for oil film thickness measurements will be developed during the study. The influence of the test parameters, a variety of lubricating oil formulations and differences in the piston ring and cylinder liner sample will be experimentally investigated, with particular emphasis on the lubricant/surface interactions. Post-test surface analyses will be included when found necessary.

The task of the Engine and vehicle research group of VTT Processes in this project is to study, by fired engine tests, the effects of modifications assessed in miniature and bench test. The power efficiency, or the fuel consumption, is the most important parameter to determine by the engine tests. Other important properties to determine are the wear, the oil temperature profile and the exhaust emissions.

The experimental work at VTT will be planned, performed and analysed in close interaction with the other partners mentioned in the project proposal. Discussions and collaboration through the COST 532 action, particularly in the field of concentrated sliding contacts, friction measurements, oil film thickness measurements, power efficiency and exhaust emissions are forecasted. The experimental results of the project will be analysed on one hand with regard to engine tribology and on the other hand with regard to more common tribological applications, for which purposes results of particular interest will be analysed using commonly accepted tribological rules and formulae and published in peer-reviewed scientific publications and conference proceedings.

Participant 2

The work at Helsinki University of Technology (HUT) is carried out at two laboratories, namely HUT Machine Design and the HUT Internal Combustion Engine Laboratory.

At HUT Machine Design the research work related to bearings is focused in two main subjects, namely extreme value tests and thin layer tests. The experimental work will be planned, performed and analysed in close interaction with the other partners of the project. The extreme value test will be carried out in particular co-operation with the Internal Combustion Engine Laboratory of Helsinki University of Technology. In the tests, the bearings are subjected to extremely high loads and sliding speeds, or insufficient lubrication. The main tribological variables in a bearing-shaft contact are measured and analysed. Discussions and collaboration through the COST 532 action, particularly in the field of journal bearings, are forecasted.

At the Internal Combustion Engine Laboratory of HUT the study will be focused on the tribology of the piston including piston rings, piston skirt, and piston pin. The demands concerning piston tribology of future engines with high cylinder pressure and/or high piston speeds at the same time with high mechanical efficiency will be considered. Computer simulations and engine tests with firing engines will be applied in the study. The experimental work will be planned, performed and analysed in close interaction with the other partners of the project. Computer simulation concerning the tribology of engine bearings will be carried out in particular co-operation with HUT Machine Design.

Discussions and collaboration through the COST 532 action, particularly in the field of piston, journal bearing and engine tribology, are forecasted. The experimental results will be analysed on one hand with regard to engine tribology and on the other hand with regard to more common tribological applications. Results of particular interest will be analysed using commonly accepted

tribological rules and formulae and published in peer-reviewed scientific publications or in proceedings of scientific conferences.

Participant 3

University of Central Lancashire will participate with investigations into oil film thickness measurements on diesel engines and oil film thickness measurements on very high speed engines, exchange of suggestions for experimental work within the project, exchange of results and discussions on the results before publication.

Participant 4

Volvo Technological Development Corporation will support the planning of the experimental work within the project, with particular reference to practical engine tribology issues, and participate in discussions on the results before publication.

Participant 5

Wärtsilä Oyj will participate in the project with support for the planning of the experimental work within the project, with particular reference to practical engine tribology issues, and participate in discussions on the results before publication.

3.4.2 Outline of work plan and time schedule

Participant 1

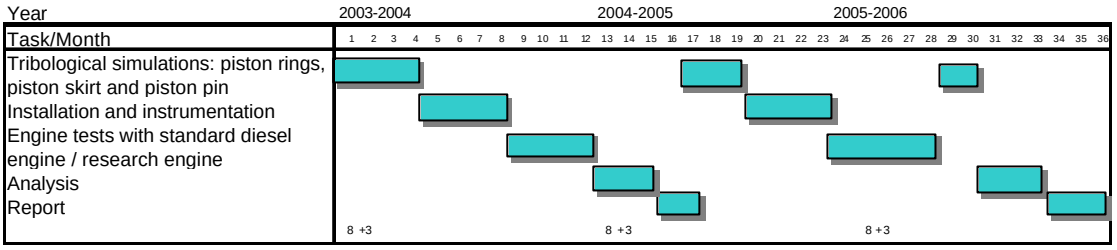
The piston ring tests at VTT Industrial Systems are scheduled for the entire duration of the proposed project. The concise plan of research, which is due to support the other piston research activities of the proposed project, will partly depend on the achievements in other parts of the project. The engine tests at VTT Processes will start shortly after the beginning of the project, and will continue throughout the entire duration of the project. The concise schedule will be determined on the basis of the progress in the other parts of the project. The work at VTT will include co-ordination of the project.

Participant 2

The extreme value tests at HUT Machine Design with the journal bearing test rig are scheduled for the years 2003 - 2004, and the thin layer tests for the years 2004 - 2005. The final research results are reported in the year 2006.

	year 2003	year 2004	year 2005	year 2006
Preparation for the extreme value tests	xxxxxx			
Extreme value tests		xxxxxxxx		
Preparation to the thin layer tests		xxxxxxxx		
Thin layer tests			xxxxxxxx	
Reports				xxxx

Outline of work plan and time schedule for the piston investigations including fired engine tests at HUT Internal Combustion Engine Laboratory:



Computer simulations on the crankshaft and connecting rod bearings will be carried out if needed during the project.

Participant 3

The experimental work to be carried out at the University of Central Lancashire will be scheduled according to the progress of the rest of the project.

Participant 4

The planned project work at Volvo Technological Development Corporation for supporting the planning and analysis of the experiments will be carried out in parallel with the progress of the experimental work of the project.

Participant 5

The planned project work at Wärtsilä Oyj for supporting the planning and analysis of the experiments will be carried out in parallel with the progress of the experimental work of the project.

3.4.3 Staff required

Participant 1

During the project two research scientists, effort 8 man/month per annum, and two technicians, effort 5 man/month per annum. Total: 39 man/months.

Participant 2

During the project four research scientists, effort 12 man/months per annum, and three technicians, effort 2 man/months per annum. Total: 42 man/months.

Participant 3...5

Sufficient resources will be allocated.

3.5 Experience and Resources of the Institutions

3.5.1 Participant 1

VTT Industrial Systems, Machine Operability has conducted tribological research continuously for 20 years. The staff involved in research related to tribology and condition monitoring includes

about 16 persons. The Tribology Laboratory presently comprises some 10 complete tribometers of various kinds, most of which have been developed in-house, located in appropriate facilities. The tribological research is supported by closely located microscopy, workshop facilities and a wide range of surface analysis and oil analysis facilities. Previous tribological research comprises, for example, coatings, ceramics, bearings, greases and piston rings.

One of the most recent additions to the test facilities is the VTT piston ring tribometer, which was developed and is being taken into use as part of the domestic research project ProMotor Engine Tribology. The piston ring tribometer has been designed as a tool for evaluating the influence of modifications in the piston ring, cylinder liner and lubricant, and the influence of the operating conditions, on the tribological performance of the piston ring and cylinder liner contact. During the piston ring tests the tribological behaviour is monitored by friction measurements and oil film thickness measurements, and after the tests the mating surfaces are evaluated by means of microscopic and profilometric methods. The first results obtained with the piston ring tribometer have been published.

VTT Processes / Engines and vehicles group is an experienced engine laboratory having modern equipment for different engine and vehicle tests. The group possesses of, for example, the M111 fuel economy test method. The same accurate equipment can be used with other gasoline engines.

The Engines and vehicles group has several engine dynamometers and two chassis dynamometers. Tests with diesel engines and vehicles are possible, however the measurements should be conducted at constant load.

Most of the work in recent years has been related to fuels, engine technology research, exhaust emissions and exhaust after- treatment.

Publications in the last two years related to engine tribology are shown under section 3.5.5 (publications 1, 2, 5-9, 10, 12).

3.5.2 Participant 2

The laboratory of Machine Design at HUT has a long tradition of research on mechanical power transmission and machine tribology. In addition to this, the laboratory has carried out internationally recognised research work in the field of biotribology. The laboratory is well-equipped with different research equipment, much of which has been designed and manufactured by the laboratory staff. The laboratory has, for example, Amsler, FZG and pin-on-disc wear testing machines. For experiments with loaded industrial gearboxes, the laboratory has two large 120 kW electric motors, which can be employed as generators. The latest machine is the versatile bearing test rig Vibrantti.

Appropriate equipment for wear measurements are equally important as a representative selection of wear test machines. The laboratory has a large amount of measuring devices, like scales, a Zeiss 3-D measurement table, surface roughness testers and various, typical mechanical workshop equipment.

The Internal Combustion Engine Laboratory of Helsinki University of Technology (ICEL/HUT) has a long and extensive experience and tradition in scientific research on internal combustion engines. Scientists working in the laboratory are particularly skilled in computer simulation, component and structure design, and experimental research employing fired engines.

The laboratory has in its possession a wide range of experimental engines that can be used for research purposes: a six-cylinder medium-speed diesel engine and several high-speed diesel engines. The laboratory furthermore possesses of a unique medium-speed, single-cylinder, extreme value research engine (EVE), which will offer facilities for experimental studies at increased brake mean effective pressure. The instrumentation of the engines will include measurements of oil film thickness between piston and cylinder, temperatures, and ring groove and inter-ring gas pressures.

The facilities for tribological engine research at ICEL/HUT have been developed during the previous Engine tribology project and, for instance, instrumentation for measurements of the oil film thickness in a main bearing of a firing engine has been taken into use. A complete measurement setup, utilizing telemetric data transmission, for measurements of oil film thickness and pressures between piston and cylinder liner has been designed and will be taken into use by the end of the year 2002. The work within the Engine tribology project has been focused on the tribology of engine bearings and piston. The study is mainly experimental, however including literature studies and bearing and piston simulations.

Publications in the last two years related to engine tribology are shown under section 3.5.5 (publications 1, 3, 4, 6, 7, 9, 11).

3.5.3 Participant 3

University of Central Lancashire, the Department of Technology, has a long tradition in tribological experimental and theoretical research on internal combustion engines.

3.5.4 Participant 4

Volvo Technological Development Corporation is part of the Volvo Corporation, which has a long tradition in the production of internal combustion engines of various size and for various purposes.

3.5.5 Participant 5

Wärtsilä Oyj has a long tradition in the production of the Wärtsilä Diesel medium speed diesel engines, which are currently used in large marine and power generation applications.

3.5.5 Previous co-operation in the field of engine tribology of Participants 1...5

The Participants 1...5 have experience of collaboration as follows: The participants 1 and 2 have acquired a significant amount of useful experience in co-operation in terms of research on the tribology of internal combustion engines, in a project entitled *Tribology of internal combustion engines* during the years 1999-2002.

During the project, discussions between the Participants 1 and 2, and Participant 3, on oil film thickness measurements, have been carried out.

The Participants 4 and 5 have participated in the project as industrial partners giving suggestions for experimental work to be carried out by the Participants 1 and 2.

The project has resulted in developments in terms of research facilities, experiences and new contacts, in a new journal bearing test rig and a new piston ring tribometer. Furthermore, the project *Tribology of internal combustion engines* has resulted in a number of publications, of which the most relevant ones are listed below:

1. Andersson, P., Kytö, M., Mustonen, M., Tamminen, J. and Valkonen, A. Tribology of internal combustion engines - A literature survey. Espoo, 2000, Helsinki University of Technology, Department of Mechanical Engineering, Publications in Machine Design 1/2000, ISBN 951-22-4915-4, ISSN 1456-4955, 133 p.

2. Andersson, P. and Sainio, H. Oscillating piston ring and cylinder liner sliding tests using a pin-on-disc tribometer. Espoo, Finland, 2000. VTT Manufacturing Technology, Report no. BVAL73-001070. 25 p.

3. Valkonen, A. Design of the crankshaft bearing test rig Vibrantti. Espoo 2001, Helsinki University of Technology, Publications in Machine Design 3/2001. ISBN 951-22-5808, 20 p.

4. Sandström C-E. Polttomoottorin kampikoneiston laakereiden tietokoneavusteinen suunnittelu (Computer aided design of crankmechanism bearings in internal combustion engines / in Finnish). Tutkimusselostus 75, Helsinki University of Technology, Publications in Internal Combustion Engine Laboratory, Espoo, 2001, 76 p.

5. Andersson, P. The VTT piston ring tribometer - A brief description. Espoo, Finland, 2001. VTT Manufacturing Technology, Report no. BVAL73-011148. 22 p.

6. Andersson, P., Blomstedt, O., Kytö, M., Sandström, C-E., Tamminen, J., Valkonen, A. and Ylöstalo, O. New facilities for testing and numerical simulation of the tribology of internal combustion engines. Tribologia - Finnish Journal of Tribology, 21(2002)1, pp. 3-19. ISSN 0780-2285.

7. Andersson, P., Blomstedt, O., Kytö, M., Sandström, C-E., Tamminen, J., Valkonen, A. and Ylöstalo, O. Diesel engine lubrication simulations and experimental research. Kunnossapito-Maintenance, 16(2002)5, pp. 38-42. ISSN 0784-1787.

8. Andersson, P. Measurements on piston ring friction using a newly developed tribometer. Paper presented at the 10th Nordic Symposium on Tribology - Nordtrib 2002, Stockholm, Sweden, 9-12 June 2002. 10 p.

9. Andersson, P., Tamminen, J. and Sandström, C-E. Piston ring tribology - a literature survey. Espoo, Finland, 2002, VTT Technical Research Centre of Finland, Research Report, in progress.

10. Kytö, M., Aakko, P., Nylund, N-O. and Niemi, A. Effect of Lubricant on Particulate Emissions of Heavy Duty Diesel Engines, SAE Paper to be presented at SAE International Powertrain & Fluid Systems Conference, October 21-24, 2002.

11. Sandström C-E. Crankshaft bearing analysis using bearing simulation software. Tribologia - Finnish Journal of Tribology, 22(2002)2-3, pp. - ISSN 0780-2285.

12. Andersson, P. Piston ring friction measurements using a new tribometer. Paper accepted for presentation at the 29th Leeds-Lyon Symposium on Tribology, Leeds, UK, 3-6 September 2002. 10 p.

3.6 Co-operation

This document is a proposal for a single project that plans to develop international collaboration through the COST mechanism.

The project consortium is looking forward to suggestions that could initiate further project co-operation with additional partners within the COST 532 action.

3.7 Research topic

The project is proposed as to be included in the WG entitled "Lubricant chemistry and chemomechanical effect".