COMBUSTION ENGINES

LUND INSTITUTE OF TECHNOLOGY

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Final report of Alvar Variable Compression Engine Development Instrument No. DE-FG01-95EE15618

0. Introduction

The Alvar engine is an invention by Mr. Alvar Gustafsson of Skarblacka, Sweden. It is a four stroke spark ignition internal combustion engine, having variable compression ratio and variable displacements. The compression ratio can be varied by means of small secondary cylinders and pistons which are communicating with the main combustion chambers. The secondary pistons can be phase shifted with respect to the main pistons. The engine is suitable for multi-fuel operation. Invention rights are held by Alvar Engine AB of Sweden, a company created to handle the development of the Alvar Engine.

A project was conceived wherein an optimised experimental engine would be built and tested to verify the advantages claimed for the Alvar engine and also to reveal possible drawbacks, if any. Alvar Engine AB appointed Gunnar Lundholm, professor of Combustion Engines at Lund University, Lund, Sweden as principal investigator. The project could be seen as having three parts:

1. Optimisation of the engine combustion chamber geometry
2. Design and manufacturing of the necessary engine parts
3. Testing of the engine in an engine laboratory

NUTEK, The Swedish Board for Industrial and Technical Development granted Gunnar Lundholm, SEK 50000 (about \$6700) to travel to the US to evaluate potential research and development facilities which seemed able to perform the different project tasks.

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The Swedish Embassy in Washington, DC, and Technical Attachés in Ann Arbor, MI, were helpful in finding these facilities.

The following were visited:

1. Massachusetts Institute of Technology, Cambridge, MA
2. Tecogen, Waltham, MA
3. South West Research Institute, San Antonio, TX
4. Intermotive Technologies Inc., Belleville, MI

MIT found interest in the Alvar engine mainly because its potential to increase power density, that is power per engine weight. MIT was selected to do the optimisation work. The decision for the design and manufacturing was made later in the project : Following the recommendation of MIT, Adiabatics, Inc. of Columbus, IN was selected for this task. The last task, engine testing was decided to be performed at Lund University.

The Alvar engine was evaluated by NIST and judged worthy of government support. On September 12, 1995, U. S. Department of Energy granted the project \$95345, and on November 8, 1995 NUTEK, The Swedish Board for Industrial and Technical Development, granted the project SEK749 000 (about \$100 000 at the time).

1. Task 1: Combustion Chamber Shape

A kick-off meeting was held at MIT at the month shift November/December 1995. People present were Professor John Heywood of MIT, Anders Hoglund of Volvo Technical Development, Gunnar Lundholm, Dr. Victor Wong of MIT and Marcus Stewart, a MIT student. The optimisation work was decided to be performed at MIT as a Masters thesis by Marcus Stewart under the supervision of Dr. Wong and Professor Heywood. Stewart would use the simulation program by Anders Hoglund of Volvo Technical Development in Gothenburg.

First task for Stewart was to validate the Hoglund program against in-house programs of MIT. For given in-data, the difference in result between the two programs was found to be negligible. Stewart now varied all possible geometrical parameters to find the combination which gives best efficiency benefits of the Alvar engine. He also investigated the knock characteristics of the combustion chamber. His M.Sc thesis "DESIGN AND ANALYSIS OF A VARIABLE-COMPRESSION RATIO INTERNAL COMBUSTION ENGINE – THE ALVAR ENGINE CONCEPT", issued in June 1997, is found as Enclosure 1. A shorter description of the modelling work and its results, written by Victor Wong, Marcus Stewart, Gunnar Lundholm and Anders Hoglund was presented at the Society of Automotive Engineers Annual Congress and Exposition by Gunnar Lundholm in February 1998, see Enclosure 2.

The MIT project study was a thorough work and it covered what was intended, i. e. secondary cylinder diameter and stroke, valve size and location, spark plug location, and piston crown geometry.

2. Task 2: Design and fabrication of prototype cylinder head

Adiabatics, Inc. was contracted to manufacture the necessary engine parts for the subsequent testing at Lund University. The latter had an test platform in use consisting of a Volvo 5 cylinder passenger car engine used with one working cylinder for variable valve timing research prior to Alvar engine testing.

Adiabatics used Mr. Melvin Woods to do the design. The cylinder head was designed to be made from a solid block of aluminium. The report for this design work is Enclosure 3.

Adiabatics then got into problems finding a machine shop which could do the work, but eventually found one. When drawings were ready in March 1997, agreed delivery time to Lund University was June 1, 1997, but the cylinder head body was actually delivered on September 16 and the last part, the secondary connecting rod, on October 2. The delay in delivery from Adiabatics was caused by design errors, problems to find a suitable workshop for the machining and problems with the selected workshop. After delivery to Lund University, several manufacturing errors were discovered, which took a laboratory engineer two weeks to correct.

In summary, this task was not satisfactorily performed, mainly due to the 4 months delay in the delivery of engine parts from Adiabatics, Inc., but also due to a number of defects in the delivered cylinder head.

3. Task 3: Build of phase control mechanism

A student group of four at Lund University took on the task of designing and building a phase control mechanism. It consists of a simple mechanical spring. The work is reported in the SAE paper 981027 (enclosure 2). The phase control mechanism was tested and the concept was proofed. The limited goal with this task thus was met.

4. Task 4: Testing of the cylinder head at Lund University:

The cylinder head and its parts were assembled to the Volvo engine test bed during November and after further modifications of the cylinder head of the oil drain and other details the testing started at December 1. A test program had been agreed with MIT and the testing followed it until it was finished on January 30. A test report, including the test program is found as Enclosure 4. This test report also reports corresponding testing with a standard engine for comparison. -This is the first time that emissions are measured for the Alvar engine.

5. Summary of the present project

The test results show that the Alvar engine has remarkably better fuel economy than the standard engine. It shows that the emissions of carbon monoxide, hydrocarbons and nitrous oxides are very similar to the standard engine (it has been feared previously that the hydrocarbon emissions would be higher for the Alvar engine due to the presence of the secondary piston).

The report finally shows that the Alvar engine can be supercharged to higher boost pressures than the standard engine and, thanks to this, give more power for a given engine size. Or, for a given power demand, an Alvar engine can be made smaller in size than a standard engine.

To summarise, the project is a technical success considering that the MIT project study was done in a professional way, the test rig was good enough to allow thorough testing of the Alvar engine characteristics, the efficiency of the Alvar engine showed to be appreciable better than a comparable standard engine, and the emissions were very similar to a standard engine.

6. Industrial interests in the past

Before the present project the Alvar Engine AB has tried to attract industrial interests in

modelling study by Ricardo Consulting Engineers in Shoreham, England. This study showed a fuel economy improvement during a typical duty cycle of 6-8% for an Alvar engine compared with a standard engine of the same size. But it also showed that if the additional benefit of the Alvar engine of being able to be supercharged to higher boost pressures would be used, the smaller size of the Alvar engine for a given power demand would give an improvement in fuel economy of the order of 25%.

During the past efforts of Alvar Engine AB to attract industrial interest it has always been met with questions for more test results, especially for emissions. Since emissions had not been measured at that time, contacted companies remained in the wait-and-see attitude.

7. Industrial interest after the present project

Recently, after the present project has been finished, a review with Volvo representatives has been held. An increased interest was noticed, and a second meeting will be held after internal discussions at Volvo. At the same time, MIT will approach one or more of the Detroit manufacturers. Alvar Engine AB also has a representative informing Japanese auto manufacturers about the project.

8. What would be a follow-on project?

As a subsequent project a multi-cylinder engine would be built with a cast cylinder head. It would be supercharged to as high pressure as possible so it can be downsized as much as possible. A phase control mechanism with feed-back control would be designed.

The cost for such a project would be in the order of \$1 000 000. Cost-sharing between a number of interested companies is a possibility. Potential sources of financing are MIT funds, NUTEK, Volvo, and Japanese auto manufacturers.

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Principal Investigator for the DOE-NUTEK Alvar Engine Project

Enclosures:

1. Stewart, Marcus: Design and Analysis of a Variable-Compression-Ratio Internal Combustion Engine – the Alvar Engine Concept. M.Sc. thesis, MIT, June 1997.
2. Wong, V. W., Stewart, M., Lundholm, G. And Hoglund, A.: Increased Power Density via Variable Compression/Displacement and Turbocharging Using the Alvar-Cycle Engine. Society of Automotive Engineers report 981027.
3. Woods, M.: Alvar Cylinder Head Design. Febr. 19, 1997.
4. Erlandsson, O. And Soderberg, F.: Results from tests with VOLVO-Alvar 1 cylinder engine. Lund University internal report, February 1998.