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UPGRADING OF ECONOMY AND RELIABILITY OF THE LOCOMOTIVE DIESEL ENGINE, SIFANG

DG/CPR/85/018

PEOPLE'S REPUBLIC OF CHINA

Technical report: Design, prototype and planning review for development of locomotive diesel engine*

Prepared for the Government of China
by the United Nations Industrial Development Organization

Based on the work of Denny Chan
UNIDO consultant

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United Nations Industrial Development Organization
Vienna

* This document has not been edited.

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Explanatory notes

Value of local currency during the period of the mission

The People's Republic of China:

100 Yuan =26.954 US$

100 US$ =371.000 Yuan

Abbreviations

AVL	AVL Gesellschaft fuer Verbrennungskraftmaschinen und Messtechnik mbH, Prof.Dr.Dr.h.c. Hans List, Graz, Austria
CICETE	The China International Centre for Economic and Technical Exchanges, Beijing, PRC
Sifang	Sifang Locomotive and Rolling Stock Works, Qingdao Shangdong Province, PRC
CTA	Chief Technical Adviser
ORE	Office de Recherches et D'Essais
UIC	L'Union Internationale des Chemins de fer, Oudenoord 60, NL 3513 EV Utrecht (Telex 70 4 69 ORE NI)

ABSTRACT

A diesel engine development project (code-named Upgrading the Economy and the Reliability of Locomotive Diesel Engine number CPR/85/018/A/01/99) was agreed upon between the People's Republic of China and the United Nations Development Program (UNDP) on March 28, 1986. A subcontract was granted to AVL Gesellschaft fuer Verbrennungskraftmaschinen und Messtechnik of Graz, Austria. This project is monitored by the China International Centre for Economic and Technical Exchange (CICETE) and the beneficiary is Sifang Locomotive and Rolling Stock Works, a manufacturing factory belonging to the Ministry of Railways of China.

The objectives of this project were to improve the performance and the reliability of a class of locomotive diesel engines of 180mm bore and 210mm stroke. An advance test facility will also be established along with technology transfers which are both much needed in this factory. Power output of this engine will be raised from 1350 hp to 1800 hp and the corresponding fuel consumption will be reduced from 170g/hp/hr to 155g/hp/hr.

There are five phases in the engine development which are Design, Detailed drawing preparation, Prototype procurement, Development work, and lastly, Endurance and qualification testings.

The first two phases have been completed and the third one is close to completion. The fourth phase, Development work, is to begin in November 1989 at AVL. The Endurance and qualification testings will be carried out in April 1990 at a temporary test facility at Sifang. The new test facility is being built but will not be ready before spring 1990.

The original project period was 37 months and the completion date was to be the end of 1989. Due to unforeseen work load and the complexity of this type of project it is estimated that from 12 to 18 more months will be needed. However, much progress has been made and morale is high amongst participants. This project will certainly come to a successful completion.

TABLE OF CONTENTS

	Page
Cover page	1
Explanatory notes	2
Abstract	3
Table of contents	4
Introduction	5
Engine block	8
Cylinder head	9
Cylinder liner	10
Piston	10
Piston ring	11
Con-rod	12
Camshaft	12
Fuel injection	13
Development program	13
Endurance testing	16
Test facility	17
Engine production	17
Conclusion and recommendation	19
Action	20
Annexes:	
Senior counterpart staff at meetings with Sifang Works, Qingdao, Shangdong province	21
Senior counterpart staff at meetings with the Ministry of Railways and CICETE of the PRC	22

INTRODUCTION

Sifang Locomotive and Rolling Stock Works located in Qingdao, the province of Shangdong, has produced over 1000 units of the IDI 12V 180 diesel engines, most of which were installed in the DFH 3 diesel hydraulic locomotives. In order to improve the power output (from 1350 hp to 1800 hp at the same rated speed of 1500 rpm), the fuel economy (from 170 g/hp/hr to 155 g/hp/hr) and the reliability (to 26000 hr between overhauls) of this engine, a technical assistance project was agreed upon between the Government of the People's Republic of China (PRC) and the United Nations Development Program (UNDP) in March 1986. This improvement is urgently needed for the present design of diesel engine because of its poor fuel consumption, short time between overhauls as well as its low specific power output that does not meet the requirements of the railway power classification.

The UNDP provided for the project an input of about 2,500,000 US$ and the Government of PRC an input of 2,500,000 RMB Yuan (in kind). The project objectives are to produce a class of locomotive diesel engines with extended life, reduced fuel consumption and higher power output. A further objective is to strengthen the capability of Sifang Works in the field of engine design, development and testing of locomotive diesel engines which will meet international standards of railway engine power classifications. This project will provide the transfer of the necessary technology and know-how which will enable Sifang Works to carry out some of the project tasks. This will be achieved through acquisition, adaptation and development of the required technology and know-how.

The project tasks are mainly carried out by Sifang Works and the subcontractor (AVL) in five distinct phases;

Phase I   Preparation of preliminary engine layouts and design.
           Preparation of final layouts and design.

Phase II Preparation of detailed drawings

Phase III Manufacturing of prototype engines

Phase IV Carrying out engine development work at AVL test stand on the prototype engine

Phase V Carrying out endurance and qualification testings in accordance with the Sifang/AVL/CTA, the UIC 100 hours and the ORE 1000 hours test cycles.

In addition, an advance test facility will be constructed at Sifang Works equipped with necessary instrumentation in order to carry out the endurance and qualification testings.

Present situation;
A subcontract was signed on July 23, 1986 between the China International Centre for Economic and Technical Exchanges (CICETE) and AVL -Gesellschaft fuer Verbrennungskraftmaschinen und Messtechnik of Graz, Austria. The contract is valid for four years from the date of signing.

Phase I started in November 1986 and was completed within 12 months. The in-line fuel injection pump used in the previous engine was found not adequate for the new engine and was replaced by a unit pump of advanced design. This major change required an increase of the subcontractor's fee of 37,500 US$ and was approved by UNDP. During the first interim meeting between Sifang Works and AVL held in April 1987, the layout of the new engine was confirmed. The final layout was verified in a second meeting in December 1987 and the detailed drawings were accepted in the third meeting in August 1988.

The first CTA, Dr. Martin Behrens from GDR was recruited by UNDP in November 1987. He came to Sifang Works in mid-November to review the project work and attended the second interim meeting at AVL. He provided many good suggestions and Sifang Works expressed their thanks for Dr. Behrens' visit.

The second CTA, Mr. Denny Chan from Canada, was recruited by UNIDO in August 1989. He went to Sifang Works in mid-August to review the project and provided technical guidance for the present and future plans for this project. This is his mission report intending to give a broad view on the actual situation of the project as well as problems and difficulties encountered during the last years in the areas of design, prototype manufacturing and communication etc.

ENGINE BLOCK

The first prototype engine block was being final machined and is about 85% completed. Final assembly is to begin in early September.

For the prototype engines, all main bearing caps will be hand-fitted to ensure good alignmemt. In production, precision machining jigs and fixtures will be employed to avoid any laborious hand-fitting. A line bore jig has been manufactured by Sifang Works at a cost of 150,000 Yuan. This jig will enable machining of camshafts and main bearing bores in one sequence thus ensuring perfect positioning with close tolerance.

The size of the main bearing shell width seemed to be smaller than most engines of this class. However, the main bearing bore size is generous at 180mm giving much room for future power upgrading. The aluminium bearing shell chosen might also provide some margin of safety for the narrow bearing shell width. Test bed evaluation will be needed to verify this design.

The main bearing cap side bolt bore (25mm) appeared to be large for the (M22 * 2) bolt making the structure less rigid. This was probably designed for a particular reason, but normally it is desirable to construct a very stiff main bearing assembly in order to resist movement at all times especially during the combustion stroke when the normal and the shear load are greatest. Combustion load is generally absorbed by the lower part of the engine block such as the side sheet, the base rail and the sump. Sifang Works has limited information on this design.

The main bearing stud (M30 * 2) appeared adequate for the combustion load. The stud material is similar to the ISO 12.9 grade. But the present thread rolling tool at Sifang Works can produce only up to the equivalence of the ISO 10.9 grade which carries less load. For better safety, it is advisable to use the ISO 12.9 grade stud. If required the CTA can arrange to provide the ISO 12.9 thread rolling tool.

CYLINDER HEAD

Basic cylinder head design is similar to the old IDI head except that the pre-combustion chamber has been eliminated and the intake/exhaust ports have been tuned. The new head looks well-proportioned and tidy.

The design of the fuel injection nozzle holder bore is complicated at least from the point of view of machining. One or two O-rings can be used to eliminate the troublesome step-boring operation. Threading in the injector sleeve can be replaced as well by a better designed swagging operation which can produce adequate sealing against combustion gas pressure.

For engines using normal ASTM 2D fuel or equivalent a valve rotator is generally not required. However if extended valve life is desirable or valve wear is excessive, an alternate valve can be selected.

Current valves are made from a single steel bar instead of the normal two-piece friction-welded construction. This is a matter of machinery availability and production practice. However, for production convenience and spare part inventory, intake and exhaust valves can be made identical with little sacrifice in engine performance.

The cylinder head flame deck height appeared to be thicker than normal providing superior mechanical strength for the current rating. For future power upgrading, it might be necessary to implement a double deck design in order to achieve low thermal loading and high mechanical strength.

For production inspection, the cylinder head can be pressurized with hot water (100 deg.C and 8 bar) for at least 5 minutes. This procedure was found to be most effective in detecting leakage in water passages and core plugs.

CYLINDER LINER

Only a small change was made in the basic design of the new cylinder liner. The liner in the IDI 180 engine had cavitation problems some time ago causing premature component change. An earlier UNDP project has helped solve this problem.

The liner flange which makes contact with the engine block requires lapping before final assembly. This procedure ensures cooling water tightness but the lapping compound might contaminate the liner inside surface causing premature piston ring/liner wear. Instead of lapping, an O-ring can be installed thus eliminating the possibility of contamination.

The honing process is very critical to liner durability. The present honing process requires one stone grid size. The CTA suggested to Sifang Works to use two grid sizes, one set coarse and one set fine. This method ensures deep oil holding valleys without sharp peaks which is an ideal environment for liner durability.

PISTON

The piston is made from two pieces, namely, a steel cap bolted to a profiled aluminium skirt. The prototype piston will be supplied by Mahle of West Germany, one of the world's leading piston manufacturers. Sifang Works has yet to receive these pistons without which the engine assembly cannot begin. Mahle said they have been shipped air freight but believed a misunderstanding with a letter of credit caused the delay.

According to a similar piston, the maximum temperature of around 350 deg C was recorded on the piston top horn area at rated load condition. The corresponding top piston ring temperature was around 200 deg C. Both of these temperatures are very comfortable for the SAE 40 grade lubricating oil. It is anticipated tnat there is no temperature problem associated with the piston. But a piston temperature test will still be needed to verify temperatures at over-load conditions.

Since the piston skirt is profiled on both the thrust and the pin sides, it is advisable to increase the piston/liner clearance for the prototype engine in order to avoid any possibility of piston scuffing. It is understood that lubricating oil consumption might be higher for the time being.

To ensure proper aiming of the piston cooling jet, Sifang Works was planning to install an external oil pump to simulate real life operation. This is a 100% inspection which requires additional equipment and it could be messy if it is not done properly. An alternate approach is to use alignment rods which have been found to be very accurate and reliable in similar engines.

PISTON RING

The piston ring set to be installed in the first prototype engine consisted of four chrome plated rings, one barrel faced compression ring, one taper compression ring, one taper with undercut oil scraper ring, and one double rail conformable oil control ring.

This set is widely used in the industry with good results. For a new engine, it is desirable to keep the ring set a little bit less tight especially for the oil rings. This precaution gives some degree of safety in avoiding piston scuffing during development work. Since information is insufficient on piston rings, it is not known if these rings have been loosened.

CON-ROD

The con-rod big end design might give rise to severe fretting problems at the joint face. The design employs a horizontal split cap with two dowell pins. One pin (olive shaped) acts as a location pin and the other takes the lateral combustion load. Exact design calculation was not available. The CTA much prefers to see either a tongue and groove or a serrated joint.

By using this design, the initial loading of the four M14 * 1.5 bolts must be quite high in order to avoid fretting. But the hardened washer (HRC 40-45) bit into the con-rod big end (HRC 26-32) when these bolts were fully torqued. An alternate design must be found. Sifang Works urged the CTA to raise this matter with AVL as soon as possible. The CTA would also undertake to calculate the optimum bolt load at the joint face.

CAMSHAFT

The prototype camshafts will be milled and turned from solid bar stock, rough grounded, heat treated and then final grounded to size. There are six sections to each engine making it quite versatile for spare part keeping.

Normally, for a prototype engine, a set of adjustable camshafts is used for development work because the final camshaft profile or valve timings are not yet known. The adjustable camshaft allows different combinations of valve overlaps to be tested as well as changes of the shapes of any of the three cams without incurring high hardware cost. Once the final cam shapes and valve timing are found, a fixed camshaft can be made, ready for the endurance testing.

Since there is no adjustable camshaft available for the development work, the CTA suggested to Sifang Works to make two additional camshafts which have different valve timings. By conducting tests with these camshafts, optimum engine performance can be found.

FUEL INJECTION

The fuel injection system was changed from the in-line pump to the unit pump design. The new design will produce better engine performance and also provide lattitude for future power upgrading. As an added bonus, this design will also facilitate engine assembly flexibility and low spare part inventory. The CTA fully agreed with this design and congratulated Sifang Works for making an excellent choice.

Initial static injection timing data was not available. Sifang Works temporarily set the first prototype engine to 20 degree BTDC as the static timing. This will enable Sifang Works to assemble the first prototype engine. When AVL receives the engine, timing can then be re-adjusted as AVL sees fit. Sifang Works would like to know how to do adjustments on injection timing. This information should be available from the pump manufacturer (Robert Bosch AG).

DEVELOPMENT PROGRAM

The first prototype engine will be assembled by mid-September then sent to AVL for the development work. The tasks in this program are as follows:

1. Measurements and set-up of the first prototype engine on the AVL test bed and measurements of initial engine characteristics, performance, specific fuel consumption, friction loss, pressures and temperatures, high pressure indicator diagrams, blow-by, specific oil consumption, smoke

values and other data according to AVL test procedure.

2. Development of combustion system in view of defined target specifications:

2.1 Development of AVL-DI-Combustion system:

optimization of the unit injection pump parameters; plunger/barrel, injection cam, delivery valve;

development of injection nozzle and injector, variation of spray geometry, spray hole number and size, injector spring characteristics;

matching of the injection line dimensions (internal and external diameter) in consideration of injection pressure and duration of the needle opening;

investigations concerning the avoidance of injection nozzle and line cavitation.

2.2 Optimization of the combustion bowl:

engine test with different basic bowl designs with regard to engine performance parameters;

tests to determine the best compression ratio.

2.3 Optimization of the inlet and exhaust ports:

test work on the test engine using the optimized experimental cylinder heads.

3. Selection and determination of fuel injection system and detail specifications of engine components from sub-supplier.

4. Optimization of turbocharger specifications:

turbocharger matching and optimization of valve timing;

variation of compressor parameters and turbine housing;

variation of exhaust pipe diameter.

5. Assessment of thermal loading of critical engine parts such as piston, cylinder head, exhaust temperatures.

6. Measurement of cylinder liner vibration in view of cavitation:

7. Stress and deformation analysis under assembly and gas loads:

main bearing wall;

main bearing cap;

cylinder head;

measurements of cylinder head gasket pressure distribution under assembly load.

8. Development of engine characteristics with regard to the performance objectives:

9. Measurement of engine exhaust emissions according to the ORE cycle regulations:

10. Performance acceptance test of defined performance values in the presence of Sifang Works respresentatives at AVL test stand:

final report covering the complete development work.

11. Review of detailed drawings according to AVL development work results: this work will be performed by Sifang Works engineers associated with AVL.

Sifang Works would like to have detailed records of the methodology used in carrying out these development tasks as well as the possibility to participate in the decision making processes during the development work period. These points are important to the continuity of this engine and for its future development. The CTA should also be closely involved during this period for his experience in engine testing can be utilized.

ENDURANCE TESTING

Sifang Works would like to know the test cycles for the 100 hours and the 1000 hours endurance tests. The CTA explained that normally these test cycles are derived from knowledge gained from the strong and weak points of the engine to be tested as well as from experience with engines in general. The intended usage and the expected duty cycle are also considered in the making of the test cycle. During the test cycle it is pertinent that all the weak points in the test engine will surface so that necessary corrections can be made.

While the ORE and the UIC test cycles are qualification tests intended for rating diesel engines of all classes in the same wav, they are by no means the most severe test cycles. The CTA will work out a test cycle for this engine for Sifang Works to consider. It will be ready for discussion during the tripartite review meeting in November 1989.

TEST FACILITY

Much of the test equipment purchased through AVL has been received in 1988 but has not been used. These items normally carry one year warranty effective from the date of receiving. At this point it is estimated that the test facility would be ready by next spring. The warranty will have expired by then. The CTA advised Sifang Works to contact suppliers to arrange for an extended warranty.

The new test cell will be located in a new building now being built but will take some time to commission. In order to carry out the endurance testings scheduled to begin in April 1990, it was decided that an existing test cell be modified to temporarily house the necessary test equipment.

It is believed that functions of some test equipment were not clear to Sifang Works, for instance the digital analyser and the fuel flow meter. It is hoped that a comprehensive list of equipment and their functions in user's language be made available to Sifang Works.

ENGINE PRODUCTION

Production of the new engine is planned for 1992, according to Sifang Works. Since the 1800 hp production rating will most likely not be available by that time, it is planned to first introduce the 1650 hp rating. With the development work going alongside the feed-back received from engines operating in the field, gradual power increase can take place. This is the best solution so far since there is an urgent and immediate need for more locomotives in China.

Presently, Sifang Works has invested up to four million Yuan in production jigs and fixtures, machinery and facilities. All of these were intended to help producing the new engine components within the factory especially for those parts currently supplied by foreign companies. However because of production difficulties and material availabilities some components must be purchased from abroad for the time being.

CONCLUSION AND RECOMMENDATION

This development program is approximately 12 months late due to the unexpected amount of work and the complexity of this type of project. It will take 12 to 18 more months to complete all the required tasks. However, the program is making very good progress towards the objectives and personnel involved are to be commended for their effort in this rather difficult project.

The CTA is concerned with a number of areas in the new engine design such as the con-rod big end joint face and the main bearing shell width. They appear to be weak in design. It will need calculations as well as performance data to verify these designs. Sifang Works felt that technical information given by AVL was insufficient. They would like the CTA to seek solutions to their concerns. The CTA was sympathetic but felt that it was a contractual matter and as such must be dealt with cautiously. He will raise this point for discussion in the up-coming tripartite review meeting as requested by Sifang Works.

The test program will be at the mid-point after the first prototype engine is assembled and shipped to AVL. The following 12 to 18 months will demonstrate whether the design is as per specifications. Sifang Works recommended that the present CTA be retained on a more frequent basis to follow through this important project to the Chinese railway transportation needs. Sifang Works would also like to communicate with the CTA via telex, fax or telephone on subjects concerning this project. The CTA will raise this matter with UNIDO and seek their approval.

ACTIONS

By CTA:

Con-rod joint face calculation verification

Fuel injection line suppliers

Endurance test cycle

Run-in cycle

Development work task requirement

Camshaft overlaps (through AVL)

AC traction for locomotives

By Sifang:

Typical locomotive duty cycles
(one for flat land and one for mountainous region)

Seek extended warranty coverage for test equipment received in 1988

Inspection report for components used in the first prototype engine

Senior counterpart staff at meetings with Sifang Works

Mr. Long Pingsheng	Vice-Director, Eng.
Mr. Liu Zheng-qi	Deputy Chief Engineer
Mr. Ji Fei	Vice-Chief Engineer
Mr. Qi Hua Jiu	Senior Engineer, Deputy Division Chief
Mr. Shi Jia-lin	Senior Engineer
Mr. Yu Song Ren	Senior Engineer
Mr. Fan Yupen	Engineer
Mr. Zheng Liang-qing	Engineer
Mr. Jin Guang	Engineer
Mr. Zhang Bai-ru	Engineer
Mr. Ye Si-gao	Engineer
Mr. Zhou YI	Engineer

Senior counterpart staff at meeting with the Ministry of Railways and CICETE

Representing the Locomotive and Rolling Stock Industry Corporation

Mr. Li Jingang	Deputy General Manager
Mr. Li Guifang	Senior Engineer
Mr. Cao Guo Bing	Engineer

Representing the Foreign Affairs Bureau

Mr. Shen Jusheng	Deputy Director
Mr. Mao Weinuo	Division Chief
Mr. Zhu Qi	Senior Engineer

Representing CICETE

Mr. Zhou Ke	Program Officer