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UPGRADING OF ECONOMY AND RELIABILITY OF THE LOCOMOTIVE DIESEL ENGINE

DG/CPR/85/018/11-01

PEOPLE'S REPUBLIC OF CHINA

Technical report: Prototype engine and planning review for development of locomotive diesel engine*

Prepared for the Government of the People's Republic of China by the United Nations Industrial Development Organization

Based on the work of Denny Chan,
UNIDO consultant

Backstopping officer: H. Seidel, Engineering Industries Branch

* 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

Republic of Austria:

100 AS =7.245 US$
100 US$ =1300.802 AS

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
UIC	L'Union Internationale des Chemins de Fer, Oudenoord 60, NL 3513 EV Utrecht (Telex 70 4 69 ORE NI)
ORE	Office de Recherches et d'Essais
FM	Friedmann & Maier Fuel Injection Equipment Co. Friedmann-Maier-Str. 7, A-5400, Hallein, Austria

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 PRC and UNDP on March 28, 1986. A subcontract was granted to AVL of Graz, Austria. This project is monitored by CICETE and the beneficiary is Sifang, a manufacturing factory belonging to the Ministry of Railways of China.

The objectives of this project are 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 transfer 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 February 1990 at AVL. The Endurance and Qualification Testings will be carried out in September 1990 at a temporary test facility at Sifang. The new test facility is being built but will not be ready before that time.

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 the completion date will be extended to the end of March 1991. A slight cost increase was envisaged and a revised budget will be submitted by Sifang.

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INTRODUCTION

Sifang Locomotive and Rolling Stock Works (Sifang) 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 170g/hp/hr to 155g/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 railway power classification.

The UNDP provided an input of about 2,500,000 US$ for the project 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 in the field of engine design, development and testing of locomotive diesel engines which will meet international standards of railway engine power classification. This project will provide the transfer of the necessary technology and know-how which will enable Sifang 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 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 testing 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 equipped with necessary instrumentation in order to carry out the endurance and qualification testing.

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 Verbrennungskraft-maschinen und Messtechnik (AVL) 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 and AVL held in April 1987, the layout of the new engine was confirmed. The final layout was verified at a second meeting in December 1987 and the detailed drawings were accepted at the third meeting in August 1988.

The first prototype engine manufacturing began in late 1988. In addition to the engine components that needed to be manufactured many new matching jigs and fixtures have been produced. New casting procedures for the engine block and cylinder head had to be developed which was a very time consuming task, but these improved parts are most important for the success of this engine.

The engine was close to being assembled in late November 1989. Afterwards, it will be shipped to Graz, Austria for AVL to carry out the performance development work. Sifang engineers will be stationed in Graz to assist AVL and to receive relevant technical training during this period. The CTA for this project, Mr. Denny Chan from Canada, was recruited by UNIDO in August 1989. He went to Sifang in mid-August to review the project and provided technical guidance for the present and future plans for this project. This is his second mission report intending to give a broad view on the actual situation of the project, as well as the progress made and difficulties encountered during the last years in the areas of prototype manufacturing and communication etc.

TRIPARTITE REVIEW MEETING

The tripartite review meeting was held on November 18, 1989 with participants from UNIDO, CICETE, Ministry of Railways and Sifang factory. The meeting was chaired by Mr. Zhou Ke from CICETE.

Sifang reported on the progress made to date including that of the first prototype engine manufacture and assembly (see Sifang progress report, November 1989). Most components for this engine have been made or were purchased. Piston assemblies, including piston rings and wrist pins, have just been received from Mahle Company of West Germany. The engine assembly work has been proceeding quite smoothly. According to the revised schedule, it will be completed and shipped to AVL in December 1989.

Sifang indicated that the project was about 12 months late. This delay was mainly due to unforseen difficulties encountered during the prototype engine manufacturing/ procurement phase. It will take about 18 more months to complete all the required tasks which will bring the final project completion date to the end of March 1991.

Considering the complexity of this project Sifang suggested to send the technical adviser, once every three months, to the development and the endurance test fields to check and coordinate the required tasks. Sifang will prepare the job description and the nomination forms for the hiring of the technical adviser.

The Backstopping Officer from UNIDO, and the chairman realized the difficulties involved in a project of this type and accepted the reasons for the 12 months delay, but reminded Sifang that extra effort and priorities should be put into this project so that the new schedule can be adhered to and project cost would not escalate further. They also urged the CTA to watch and coordinate closely those remaining tasks for he was also responsible for the success or failure of this project.

PROTOTYPE ENGINE MANUFACTURING

Sifang received two crates of pistons and accessories from Mahle Company in West Germany. There are 15 sets of completely finished piston assemblies compiled of cap and skirt, pin and rings. There were 17 more pistons of incomplete machining. These are, according to the purchase order, to be retained by Mahle until the final piston skirt profile is determined from the performance test results obtained from the first prototype engine. The CTA later found out that Mahle shipped these unfinished pistons purposely to Sifang in order to invoice CICETE for the whole purchase order. Otherwise they would have to wait until the final skirt profile is determined before they would get paid. This is not an acceptable business practice and air freighting these heavy components to Sifang was very costly to the project. Sifang was asked to ship these pistons back to Europe, to AVL, along with the first prototype engine.

The con-rod small end bushings were also received from Miba Company in Austria. Because of their taper ends, Sifang has made a special jig for installation to the con-rod. Since the bushing requires an interference fit, liquid CO2 was used to chill it down to a clearance fit before installing it to the con-rod. This operation needs good timing and precise orientation of the mating parts. The CTA suggested that an alignment tool be made on top of the installing jig so that the lube oil holes on both the bushing and the con-rod small end bore will align.

To obtain additional endurance strength, all con-rod surfaces were polished after final machining.

The assembly load-induced plastic deformation marks on the con-rod big end bolt seats reported by Sifang were discussed with AVL engineers. Incidentally, AVL has also noticed something peculiar at the con-rod big end when they were doing the static engine block stress analysis. They felt that either those big end bolts were stretching or the internal threads in the con-rod were deforming under normal assembly load. This problem was not further investigated nor was it formally reported to Sifang at that date because there was not sufficient time. Also, con-rod stress analysis was not a required task in the contract. AVL engineers suggested that Sifang should investigate materials and heat treatments used for the con-rod and the con-rod bolts. AVL would also check these components metallurgically against drawing specifications.

For the con-rod big end joint face design over which both the CTA and Sifang have expressed concerns, AVL reassured the CTA that it was a good design. AVL has used this design successfully on other engines such as the Caterpillar 3600 and the KHD 628 engines both of which are current series production engines. No con-rod failure has ever been reported with these engines. AVL would like to do a stress analysis to prove the design calculation is correct, if there are funds available in the budget.

Results obtained from the static engine block stress analysis showed that the safety factor was above 2.6 for the basic GG 25 block material and up to 11.5 for the GGG 60 main bearing cap material. However, high stress concentration was found around the fuel injector holder locating recess. This was not a serious problem since the recess can easily be relocated or eliminated. AVL was very pleased with this engine block design.

Since the factor of safety was very high for the main bearing cap due to the high quality iron alloy GGG 60, the CTA asked AVL, in order to reduce production cost, if the engine block material (GG 25) could be used for the main bearing cap without sacrificing much of the safety factor. AVL would not recommend the change based on their experience.

FUEL INJECTION EQUIPMENT

A progress review meeting was held with Friedmann & Maier (FM) Company in Salzburg, Austria, a subsidiary of Robert Bosch AG of West Germany. FM is the supplier for the unit injection pump and injection nozzle for the two prototype engines. This small Austrian fuel injection equipment manufacturer was recently sold to Bosch AG of West Germany thus enabling FM to tap the vast technology base that Bosch possesses. This project will also benefit from this change.

The original design criteria for the fuel injection equipment was specified by AVL based on current engine requirements such as external dimensions, fuel flow, needle opening pressure, maximum injection pressure and exhaust emissions.

Basic specifications for the equipment were 16mm plunger diameter, 1200 bars maximum injection pressure, 270 bars opening pressure, 3mm inside diameter high pressure line; final nozzle tips configuration to be decided from engine performance test results. The CTA felt that the 1200 bars maximum injection pressure is sufficient for the present engine but many engine manufacturers are increasing it to 1500 bars in order to get better performance. Sifang should keep this in mind.

FM did not have an existing product to satisfy AVL's requirements but was willing to modify one of their basic designs to suit. According to FM, the development cost was not large since it was possible to utilize many components from their production assemblies. Components such as plunger and barrel, injector tip housing, for example, are interchangeable with other unit pump families. Prototype components were produced in the fall 1989. Some pumps have been assembled.

To ensure that their products will meet the design requirements, a simulated test will be carried out by FM development engineers. This test involves putting a complete fuel injection assembly on a specially constructed test stand. This assembly includes a camshaft machined with the profile supplied by AVL, and it was being manufactured by Bosch in Stuttgart, West Germany. Basic fuel injection characteristics such as nozzle opening pressure, needle lift, injection pressure, secondary injection, line cavitation and fuel flow will be thoroughly investigated and optimized.

FM estimated that this work would be completed by mid-March 1990. However, their work will not hinder the engine development phase scheduled to be carried out next February. They will discuss test results and progress periodically with AVL.

ENGINE PERFORMANCE DEVELOPMENT

With the news that the first prototype engine will be shipped by December 1989, AVL began to finalize the installation of the special test facilities required to test an engine of this size. These are mainly load absorbing system, intake and exhaust ductings.

There are no fixed rules and rigid procedures for testing and developing an engine. For documentation purposes, AVL and the CTA have agreed to follow a general performance development schedule. This schedule is subject to approval from Sifang.

The tentative performance development schedule is as follows:

RUN-IN

1 Disassemble engine

2 Measure all major component dimensions

3 Reassemble engine, fit specially made main bearing shells if main bores are out of round, fit fuel injection lines, set static injection timing.

4 Transport engine to test cell.

5 Connect and calibrate instrumentation.

6 Start up engine and run at idle for 30 to 60 minutes Record engine data.

7 Stop engine to check main bearings and valve lashes.

8 Restart engine and run it along the propeller load curve at 5% load/speed increment for 16 hours. During this period, record engine data at every load/speed increment, check bearing shells at least two times, once at mid-load and once before maximum load is applied. Collect and analyze lube oil samples.

9 Stop engine, remove two or three power assemblies. Inspect contact patterns on piston skirts, piston rings and liners. Check wear marks on valves, valve seats and guides.

10 Reassemble engine.

OPTIMIZATION

Data collected during the run-in period must be thoroughly analyzed to maximize efforts in the engine optimization.

Depending on the run-in results, pistons used in the prototype engine might have to be sent to Mahle Company for modification of skirt profile. Reg ·dless of the results, all remaining rough-machined pistons from the second crate will be sent back to Mahle Company for final machining.

General task outline for the engine optimization is a follows:

Select fuel spray angle and nozzle hole diameter to get minimum fuel consumption and smoke density.

Eliminate secondary injection by matching the high pressure line and the delivery valve.

Boost pressure will be optimized to operate at the design target value.

Up to three turbocharger builds will be tried out to minimize firing pressure and exhaust temperature.

Fuel injection timing may also be adjusted to match the boost pressure.

High altitude turbocharger operation will be simulated.

ENDURANCE TEST CYCLE

According to the statements of work in the subcontract with AVL, endurance running of the prototype engines will be carried out at Sifang test facilities. AVL shall assist in the write-up of the test procedures and the test data analysis.

This subject was discussed at length with Mr. G. Athenstaedt, Manager of Development at AVL. It was agreed that it is not necessary at this stage to run different endurance test cycles separately since the real objective of this type of test is to verify that major components in the prototype engine can survive some reasonable period of running under an arbitrarily chosen load cycle. Even though these test cycles are chosen based on experience and typical real life duty cycles, there is no actual indication after the completion of the test that the engine will or will not have a long life. However, it is important and necessary to run the UIC 100 and the 360 hours in order to qualify the engine for international recognition.

At the conclusion of the discussion it was agreed to propose to Sifang to combine all three test cycles into one 1000 hour test period.

The endurance test will begin with the UIC 100 hour test cycle. After it is completed, the test engine will be disassembled for component examinations. All relevant components such as piston rings, liner, valves and all bearings etc. will be dimensionally measured and photographed. This will be a time-consuming task. Then, the engine will be reassembled with all original components and the UIC 360 hour test cycle started, the same after-test engine component examinations will be repeated. It is necessary to keep a record of all dimensions for they will indicate the approximate wear rates of the engine. The same procedure will be repeated for the remainder of the 1000 hours with a different test cycle. This cycle will be determined based on the initial performance data obtained from the first prototype engine.

This proposed 1000 hour test run will not only enable an earlier release of the engine for production, it actually will save more than 460 hours worth of fuel, electricity as well as many hundreds of man-hours.

TEST EQUIPMENT

Warranty for those pieces of equipment purchased and delivered in 1988 has expired for quite some time. Sifang would like to obtain an extended warranty coverage for this equipment which would not be used until later next year.

According to Mr. Krebl, manager of Sales from AVL, all AVL products carry a 12 months warranty from the date of receiving and there is no official extended warranty policy. However, Mr.Krebl indicated that, since the equipment has not been used, AVL would replace any component that is found to be defective due to poor workmanship at the time of installation.

When Sifang is ready to install the equipment, an AVL service representative will be dispatched to the job site to carry out a final system check and power-up. He will assist Sifang personnel in the installation if required. Four weeks notice will be required for dispatching the service representative.

The CTA suggested that Sifang personnel carry out the installation by themselves as much as possible, for this is the best opportunity to get familiar with the whole test facility. Experience gained from this exercise not only can better equip Sifang to perform system diagnostics but can also help to avoid prolonged facility shutdown due to long lead time for dispatching a service representative from abroad.

CONCLUSION AND RECOMMENDATIONS

This development program is approximately 12 months late due to the unexpected amount of work and the complexity of this type of project. The original project estimate did not take into account the amount of time needed to develop new castings for the engine block, cylinder head and other iron-based components. According to the latest estimate, the project completion date will be at the end of March 1991. 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.

Meetings with AVL engineers and management held at Graz were very constructive. Many issues were resolved. AVL was thankful that they had an opportunity to discuss objectively, details of this project with the CTA. They believed that the active participation of the CTA would greatly enhance the outcome of this project.

AVL was contemplating a 12% cost increase resulting from the delay. The CTA pointed out to AVL that this increase was not justifiable for AVL was partially responsible for the delay. Even though AVL was not directly in charge of the prototype procurement phase, more guidance and assistance should have been extended to Sifang. AVL withdrew the demand.
Concerning the con-rod weak appearance, AVL cited several

current engines using this design with good service records. AVL would like to carry out a detailed stress analysis in order to convince both Sifang and the CTA that the design is perfectly sound. However, additional funding would be needed and the CTA recommended such funding be allocated.

Stress analysis work for the engine block and the cylinder liner has been carried out by AVL. Analysis results indicate that factors of safety ranging from 2.6 to 11.5 were measured in these components. The nozzle holder locating recess was the only area that AVL recommended to be changed because of high stress concentration.

AVL does not have an official extended warranty for their test equipment. For those pieces of equipment delivered in 1988, a verbal agreement was made that AVL would replace free of charge defective parts due to poor workmanship. All equipment will be checked and started up by an AVL service representative at time of installation.

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 recommended that the present CTA be retained on a more frequent basis to monitor and coordinate this important project to the Chinese railway transportation needs.

ACTION

By CTA:

Provide suppliers for fuel injection line

Check grade 12.9 thread rolling die availability

Obtain information on AC traction for locomotives

By Sifang:

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

Prepare inspection report for components used in the first prototype engine

Prepare job description and nomination forms for hiring the CTA

ANNEXES

Senior counterpart staff at meeting with UNDP Beijing

Mrs. Zhang Xi Wei	Program Officer
Mr. S. Murata	Assistant Resident Representative
Mr. Li Shaoyi	Program Officer

Senior counterpart staff at meetings with UNIDO Vienna

Mr. H. Seidel	Backstopping Officer
Mr. A. Hadeiba	Recruitment Officer

Senior counterpart staff at meetings with Sifang Works

Mr. Qi Wei	Director, Eng.
Mr. Long Pingsheng	Vice-Director, Eng.
Mr. Liu Zheng-qi	Deputy Chief Engineer
Mr. Ji Pei	Vice-Chief Engineer
Mr. Qi Hua Jiu	Senior Eng., Deputy Division Chief
Mr. Shi Jia-lin	Senior Engineer
Mr. Yu Song Ren	Senior 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 meetings 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. Mao Weinuo	Division Chief
Mr. Zhu Qi	Senior Engineer

Representing CICETE:

Mr. Li Ming	Deputy Division Chief
Mr. Zhou Ke	Program Officer
Mr. Lioa	Program Officer

Senior counterpart staff at meetings with AVL

Mr. Sucher	Deputy Vice-President
Mr. Kling	Chief Engineer, Design II
Mr. Pfeiffer	Staff Engineer
Mr. Herzog	Senior Project Engineer
Mr. Athenstaedt	Manager, Development Dept.
Dr. Landfahrer	Manager, Thermodynamics Dept.
Mr. Maier	Project Coordinator
Mr. Krebl	Manager, Sales

Senior counterpart staff at meetings with FM

Dr. Bodzak	Application & Research Dept.
Mr. Simon	Technical Sales Representative
Mr. Kinzel	Dept. Head, Application