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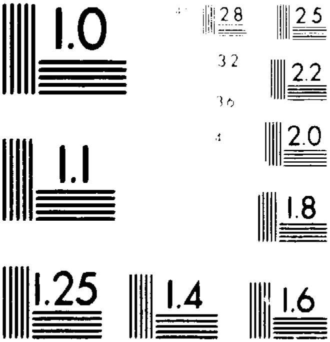

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India

DESIGN AND DEVELOPMENT OF INTERNAL COMBUSTION ENGINES FOR APPLICATION IN TWO- AND THREE-WHEELERS

UC/IND/79/038

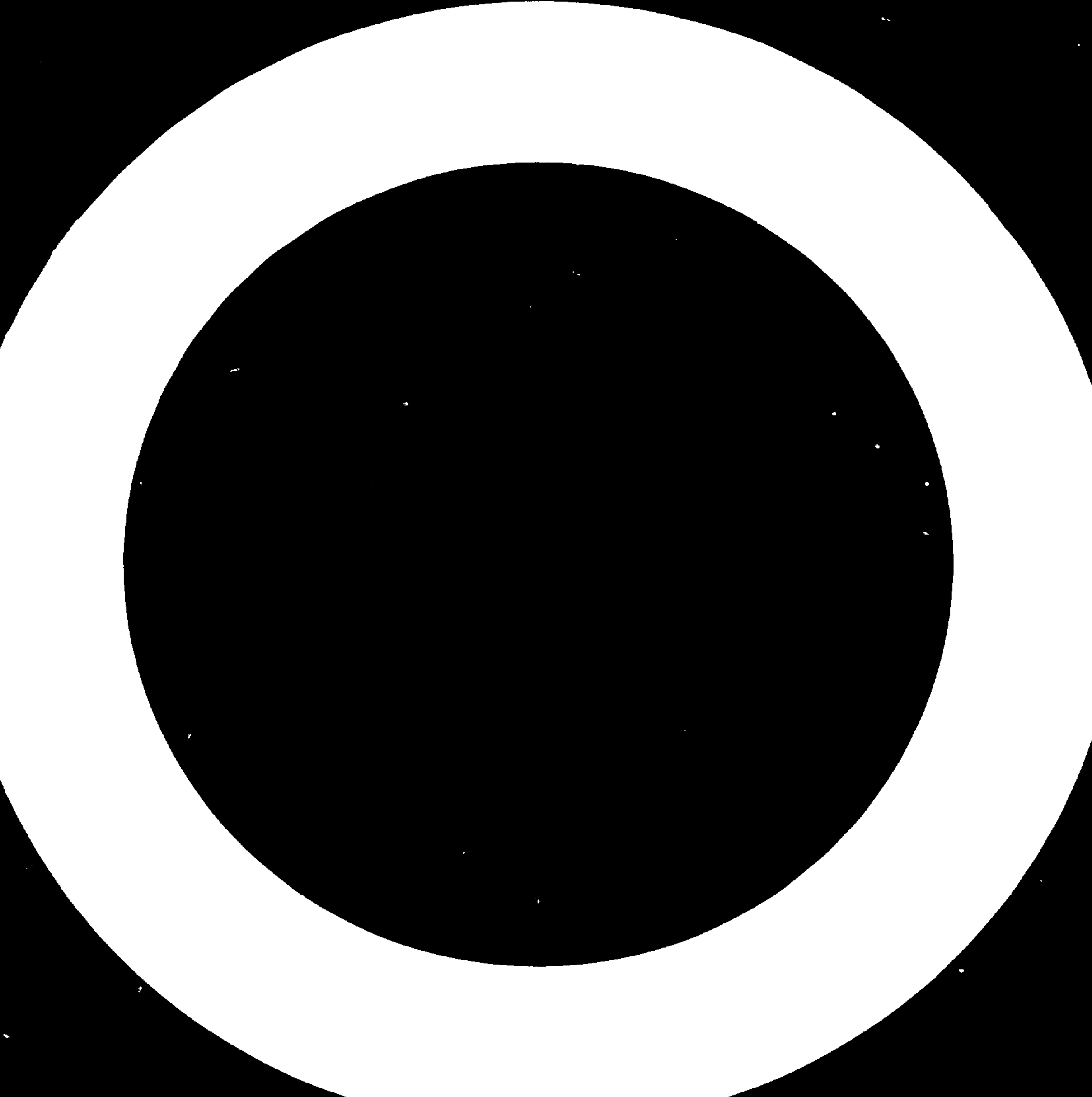
INDIA

Mission report

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

Based on the work of Stanislaw Radzimirski,
expert in the design and development of internal
combustion engines for application in two- and three-wheelers

V.84-85225



ABSTRACT

As part of the project "Design and development of internal combustion engines for application in two- and three-wheelers" (UC/IND/79/038), the United Nations Industrial Development Organization (UNIDO), acting as executing agency for the United Nations Development Programme (UNDP), sent an expert to Poona, India, for 12 months from 18 April 1983 to 17 April 1984.

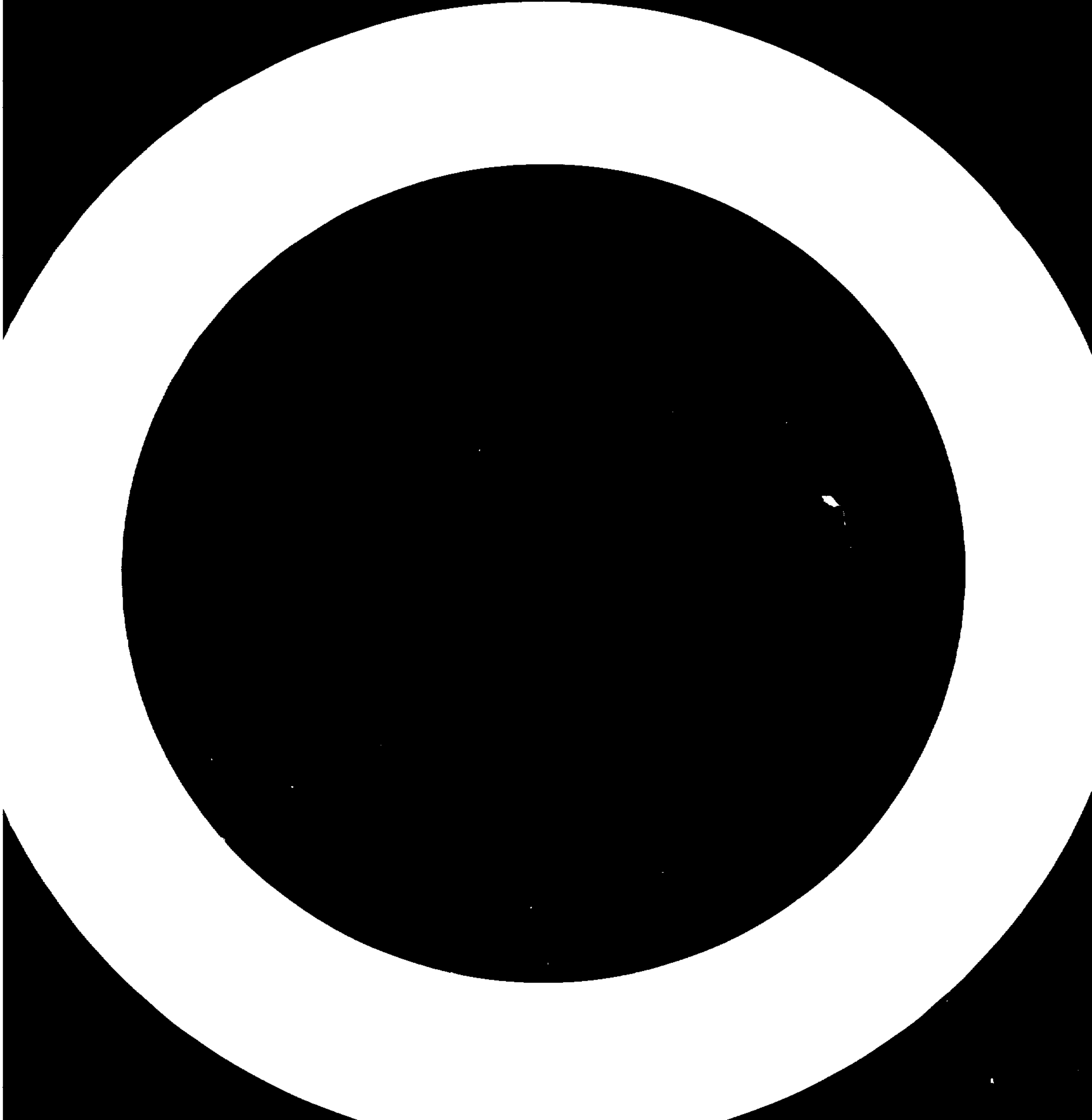
The expert was attached to the Automotive Research Association of India (ARAI) where, in accordance with the job description his duties were:

(a) To design and develop an internal combustion engine for optimal fuel consumption and reliability under operating conditions in the country; this development should be an acceptable power unit for a motorized cycle rickshaw, which has a large potential as a transport vehicle in metropolitan, suburban and rural areas;

(b) To train ARAI counterpart technical personnel in engine design technology.

Regarding the first task, experimental work on the development of a 100-cc two-stroke engine for scooters was completed. The result was an improvement in power of 26 per cent and in fuel consumption of 20-40 per cent. Work on the development of a 150-cc two-stroke engine for scooters was initiated, the engine evaluation was completed and the main areas where improvement was required were located. This work is now being carried out at ARAI. Work aimed at the development of a fuel-efficient four-stroke engine as an acceptable power unit for two-wheelers and motorized rickshaws was initiated and the first phase of engine design completed. The work on intake systems for two-stroke engines and the selection of engines for motorized rickshaws developed at ARAI was also carried out. Also, consultancies for the improvement of engines and their components for two- and three-wheelers were given to eight manufacturers.

Regarding the second task, on-the-job training of ARAI technical personnel took place by consultancies and discussions. Project engineers and technical assistants were trained in different fields of development, design, testing of engines and their components.



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INTRODUCTION

As part of the project "Design and development of internal combustion engines for application in two- and three-wheelers" (UC/IND/79/038), the United Nations Development Organization (UNIDO), acting as executing agency for the United Nations Development Programme (UNDP), sent an expert to Poona, India, for 12 months from 18 April 1983 to 17 April 1984.

The expert was attached to the Automative Research Association of India (ARAI), whose work is aimed at improving existing Indian power units for two- and three-wheelers, particularly with regard to fuel economy, and establishing facilities for design and development of engines better suited to the conditions in India and to future requirements as to fuel consumption and air pollution. The total duration of the work is expected to be from two-and-a-half to three years. It started mid-1983. The main tasks of the expert were as follows:

(a) Improvement of the performance of a two-stroke engine for scooters;

(b) Development of inlet systems for small engines;

(c) Improvement of a four-stroke engine for mopeds;

(d) Design and development of a four-stroke engine for motorcycles;

(e) Selection of an engine for motorized rickshaws;

(f) Consultancy for Indian manufacturers of small two- and four-stroke engines and engine components;

(g) Consultancy for ARAI in engine and vehicle development, research and design;

(h) Training of ARAI technical personnel.

The work noted under (a), (c) and (d) was expected to be sponsored by the industry. In the end, the manufacturer of a four-stroke engine for mopeds did not approve the feasibility report and cost estimate worked out by ARAI. Instead, work on the development of a two-stroke 150-cc engine for scooters was sponsored by another manufacturer and followed up at ARAI. The work on the design and development of a four-stroke engine for motorcycles was not sponsored either. In view of the importance of the problem, ARAI decided to do this work and finance it from its own budget. Work started in November instead of in August 1983.

In India, two-wheelers fitted mostly with two-stroke engines account for more than 50 per cent of the total petrol consumption. This is extremely high compared to that in developed countries where the share of small two-stroke engines is hardly more than 2 per cent. These proportions show that India is especially interested in improving two- and three-wheeler fuel economy, therefore, the examination of the possibility of reducing fuel consumption of Indian two-stroke engines was included in the programme of the expert. This examination was a continuation of the study undertaken during his first mission in 1981.

Many projects taken up at ARAI are sponsored by manufacturers and are strictly confidential, therefore, at the request of ARAI, the names of the manufacturers and trade names of vehicles subjected to tests were deliberately omitted from this report.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

1. Two- and three-wheelers mostly equipped with two-stroke engines account for a considerable part of the total petrol consumption by vehicles in India, and therefore special attention should be paid to their fuel economy, which in some current models could be significantly improved without major engine modifications. Improvements could be made in the adaptation of engines, mostly of foreign origin, to Indian conditions. In many cases the design and adjustment of engines developed in the 1950s and 1960s are not optimum to fuel economy, and specifications on material quality, dimensions, assembly, adjustment etc. are often not conformed to.

2. Improvements in engine fuel economy could be made mostly in the following areas: carburation, adjustment of the engine compression ratio to anti-knock properties of available fuel, air filtration, cylinder port timing and exhaust system. Improvements made to one of the engine models at ARAI showed that in extreme cases the reduction of fuel consumption was as high as 20-40 per cent. This was achieved with minor engine modifications. There are many possibilities for an improvement in fuel economy in other engine models.

Recommendations

1. A project should be started aimed at improving the fuel economy of basic two- and three-wheelers based on the findings shown in chapter IX of this report. The work should be carried out at ARAI. Apart from fuel consumption, the problem of air pollution, which is becoming more and more important, should be taken into account.

2. The testing facilities of manufacturers should be developed. In the meantime the manufacturers should take advantage of the testing facilities at ARAI.

3. A course should be held in two-stroke engines for the research and development (R and D) personnel of manufacturers with lectures to be delivered by foreign and Indian experts. A text book should be published with the assistance of UNDP on the theory, design and testing of two-stroke spark ignition engines.

4. The procedure used for fuel-economy tests specified by governmental regulations should be modified. Vehicles to be tested should be drawn at random by representatives of the technical centre instead of being chosen by manufacturers.

5. The automotive ancillary industry should put into production components developed specifically for Indian conditions, which require efficient fuel and air filtration. It is necessary to develop pressure die-cast aluminium alloy cylinders with cast-iron sleeves and to increase the use of reed valves in intake systems. Also, carburettor inspection facilities should be developed, particularly flow-rigs, which will make it possible to tighten production tolerances, reduce the variation in mixture strength for carburettors and thus the variation in engine performance.

6. The present ARAI basic testing facilities for small engines should be expanded by at least two dynamo meters, which will be supplied by UNIDO. Also, facilities should be developed in the area of carburation e.g. steady flow-rig and jet calibration devices.

7. Work should be continued on the following:

(a) Design and development of a four-stroke engine, mostly for use in three-wheelers;

(b) Survey and development of air filtration systems;

(c) Design and development of carburettors with balanced float chambers.

I. IMPROVEMENT OF THE PERFORMANCE OF A 100-CC TWO-STROKE ENGINE FOR SCOOTERS

After production of scooters with a 100-cc engine started in 1982, there were complaints from customers relating to poor fuel economy and inadequate performance. In order to identify the weak points of the engine, an evaluation of a scooter was carried out at ARAI. It was found that there was a high inconsistency in fuel consumption and poor fuel economy at higher speeds, and a very low performance at full throttle in the whole range of engine speeds; lower by 15-25 per cent than that specified by the manufacturer.

Work started at the end of May 1983 and took eight months. In order to locate the causes of the poor performance, the engine design and manufacturing quality were studied and extensive tests of engine beds, scooters on the road and the air filters on the filter-flow-rig were carried out. Altogether six engines and three scooters were subjected to tests. The main findings were as follows:

(a) The low and inconsistent performance of the engines was caused by the fact that engines from current production did not comply with the specifications on port timings, compression ratio, cylinder-block casting quality and some other factors;

(b) The specified port timings were not optimum for current production: their tolerances were too wide;

(c) The tolerance of the distance between the cylinder block top face and the piston crown edge at top centre was too wide and so was the tolerance of the compression ratio. These resulted in a high variation in engine performance;

(d) The setting of the carburettor was not correct. The air-fuel mixture delivered was extremely rich, particularly at idle and part-load in the range of medium and higher speeds, which resulted in a high fuel consumption.

In order to improve the performance, the following rectifications and modifications were introduced:

(a) The optimum timings of exhaust, inlet and transfer ports were set;

(b) The shape of the exhaust port was modified;

(c) The tolerances of the main parameters affecting intake, scavenging and combustion processes were narrowed;

(d) The defects in engine execution, particularly in the cylinder block, were rectified;

(e) A new optimum idle setting of the carburettor was selected;

(f) The jet needles in the carburettor and intake system were optimized.

The total effect of improvement work was as follows:

(a) The maximum power of engines supplied to ARAI by the manufacturer for improvement was 3.5 hp at crankshaft, it was increased up to 4.3-4.5 hp (the value specified by the manufacturer), i.e. the total average increase was 26 per cent;

(b) The fuel consumption of the scooters supplied was: 53-56 km/l at 30 km/h; 45 km/l at 40 km/h; and 32-35 km/l at 50 km/h; the fuel economy with the modified engines was improved to 68 km/l at 30 km/h; 57 km/l at 40 km/h; and 46 km/l at 50 km/h. The total improvement amounted to 20-40 per cent;

(c) The engine-to-engine variation in power was reduced from the initial value of 15-20 per cent to about 5-7 per cent.

Three comprehensive technical reports of findings and recommendations were given to the manufacturer. Two visits were paid to the factory, and the manufacturer's representatives were in constant touch with ARAI. The first recommendations on casting quality of the cylinder block, port timings and idle setting of the carburettors were put into effect in production during the period from October 1983 to January 1984. They resulted in a considerable improvement in the performance of the engine and the scooter. The remaining recommendations are being implemented. All improvements were incorporated into production by May 1984.

The manufacturer was also given recommendations on how to increase the power output to 5.0 hp if it is required in order to make the scooter more competitive with the new models that are scheduled to enter the market in the coming months. For this purpose it will be necessary to modify the exhaust, inlet and cooling systems and increase the compression ratio, which is feasible with the higher octane petrol recently introduced in India.

Before the improvement tests started, a new test-cell for small engines was set up, and equipment was installed and calibrated. Improvement of the performance of a 100-cc two-stroke engine for scooters was the main task. It served as proof that there was a wide scope for improvement in the fuel economy of some engines and that it was possible to reduce fuel consumption by introducing minor modifications. The basic training of ARAI technical personnel took place within the framework of this project. Moreover, acquired experience is being used for the development of a 150-cc engine for scooters.

II. DEVELOPMENT OF INLET SYSTEMS FOR SMALL ENGINES

The following work was carried out on inlet systems for small two-stroke engines in the framework of this project.

Modification of the existing air-filter rig

The air-filter testing facilities were initially set up for car and truck filters. In 1981, the rig was partially adapted to testing air-filters for small two-stroke engines. However, it turned out that the extent of adaptation was insufficient, in particular, the dust-feeding method was not fully suitable for testing small filters, it resulted in high measurement errors and poor repeatability. The efficiency was often as low as 50-60 per cent which, taking into account that the filters tested were made of paper, seemed too low. A thorough examination of the factors affecting the measured efficiency was made and several shortcomings were discovered: (a) the dust was fed by hand not carefully enough and there were uncounted dust losses; (b) the chamber in which filters were placed in the rig was too big and its walls too coarse, which made it impossible to collect all the deposited dust; and (c) the collection of the deposited dust was done by brushing and was not sufficiently thorough.

In order to remove these defects the following modifications were introduced in the rig: (a) an automatic device was developed and used for dust feeding; (b) the shape of the filter chamber was changed; and (c) instead of collecting the deposited dust by brushing, the whole chamber and the feeding device were weighed before and after tests, which practically eliminated dust losses. These modifications increased the measured efficiency of the same filter models from about 50-60 per cent to about 90-95 per cent, which is almost normal for paper filters of small engines.

Survey of the air filters used in India

In India, the concentration of dust in the air is higher by a factor of 5-6 than in Europe. This makes special demands on filter quality. Designs developed in Europe are often inadequate for conditions in India. In order to examine the quality, four different makes of filter used in India for 100-cc and 150-cc engines were tested on the rig. Their dust-retaining efficiency varied considerably from 67 to 95 per cent. The ratio of the highest to the lowest capacity for the same vehicle model was 2:1. In general, the filters with the poorest efficiency had the lowest dust-retaining capacity.

The vehicle manufacturers concerned were informed of the results of the survey and were requested not to recommend the inferior filters (less than 90 per cent) for use in their vehicles.

The tests also showed that the dust-retaining capacity of filters used in some models of vehicle was low, which resulted from their low specific area. These findings applied mainly to vehicles of European origin, which were not adapted to conditions in India. The life-time of such filters is short, which means high fuel consumption due to clogging, and the situation is aggravated by poor filter maintenance. The vehicle manufacturers concerned were contacted and filters with higher specific area were recommended to be used as far as possible. One of the filter producers responded by building prototypes of filters with an increased area, which were tested at ARAI. Preliminary tests showed that one of them was satisfactory; more thorough tests are going to be conducted. Two technical reports were sent to the manufacturers.

Flow-rig for carburettor testing

The concept of the flow-rig for carburettor testing was worked out and a draft design completed; suitable indigenous equipment was selected and ordered. However, the delay in the supply of a vacuum pump, which is one of the basic components of the rig, made it impossible to set up the facilities during the expert's stay in Poona. The work will continue after the vacuum pump has been delivered.

Study of the design of existing carburettors

Strength of air-fuel mixture

The objective of the study, which covered only about half of the Indian two-stroke engine models, was to examine whether the strength of the air-fuel mixture delivered by the carburettors complied with the requirements of different engines, and to find ways to improve it. In order to determine the mixture requirements, two methods were developed: (a) measuring the strength of the air-fuel mixture on the engine-bed and the vehicle; and (b) measuring the air-fuel ratio change on firing engines.

The mixture requirements for basic two-wheeler models were determined at full throttle, under cruising conditions and at idle. Then different models were used to verify whether the actual mixture strength complied with the set requirements. In three out of six models the mixture was considerably richer than that required for optimum fuel economy, particularly under cruising conditions, because the carburettor setting was not correct. There is scope for improvement in fuel economy by optimizing the engine carburation. It is estimated that it is possible to reduce fuel consumption by up to 20 or even 30 per cent by minor carburettor modifications. This was confirmed by the improvement obtained on the 100-cc two-stroke engine for scooters. The extent of modification depends on the carburettor design and must be selected individually for each engine model. The examination of carburettors with a sliding valve, which are in use in the majority of Indian two-stroke engines, showed that the modification consisted of replacing one-stage jet needles by two-stage ones.

It is advisable to compare the actual mixture strength in all models to mixture requirements. Moreover, it is necessary to introduce modifications on the carburation side in case the air-fuel ratio is not optimum. Such modifications have been already introduced in the 100-cc engine for scooters and are being tested in the 150-cc engine.

Balanced and unbalanced float chambers

The carburettor with a balanced (internally vented) float chamber has advantages over one with an unbalanced (externally vented) one, with which carburettors used in India are fitted. In the case of an unbalanced chamber, the air-fuel mixture strength, i.e. the fuel consumption, depends to a great extent on flow resistance in the air filter. The choking of the filter, inevitable in service, results in mixture enrichment and a decrease in fuel economy. Tests carried out on the 100-cc engine showed that in the case of proper filter maintenance, i.e. if the filter is replaced after the number of kilometers recommended by the manufacturer, the rise in fuel consumption amounts to 14 per cent. If the maintenance is not satisfactory, it may exceed

20 per cent. In the case of a balanced chamber, the increase in fuel consumption due to air-filter clogging is very low. The fuel economy resulting from replacing an unbalanced by a balanced float chamber averages 7-8 per cent.

In order to switch from an unbalanced to a balanced chamber in the carburettors under current production, it will be necessary to change the basic setting (jets, needles, air bleeds); to modify the progression system; and to solve the problem of hot engine start up.

The concept of a balanced float chamber for one of the carburettor models was worked out at ARAI and a prototype executed. Preliminary tests showed that it was functioning properly. The work on the optimization of the carburettor setting started in February, but stopped because the tester necessary for that purpose had broken down and the new tester had not arrived. The work will be continued by ARAI after the new tester has been supplied.

III. IMPROVEMENT OF A 150-CC TWO-STROKE ENGINE FOR SCOOTERS

The improvement of a 150-cc two-stroke engine for scooters was substituted for the improvement of a four-stroke engine for mopeds, which was not sponsored by the manufacturer. Work started in October 1983. The main objective was to improve the fuel economy by an average of 20 per cent, and particularly to reduce the fuel consumption at a speed of 40 km/h from the present value of 45 km/l to 55 km/l, thus meeting the requirements for fuel economy laid down by the Government of India. Modifications introduced for this purpose should not adversely affect the life-time of the engine and should improve the acceleration.

The work was divided into two phases: (a) evaluation of the engine performance and durability and identification of areas where improvements were feasible without major modifications; and (b) modification of the engine in order to meet the requirements for fuel economy and to improve the acceleration.

The first phase was completed in February 1984. The collected data will serve as the reference basis for further work. Two engines were tested. It was found that the actual maximum power output was 15 per cent lower than that specified by the manufacturer. The difference between the specified and actual maximum torque was 7 per cent. The following main deviations in engine execution affecting the performance were found: (a) the port timings were not within specifications; (b) the compression rate was lower than that specified; and (c) the air-fuel mixture was too rich at part load.

On the basis of these findings, the programme of improvement work was laid down as follows:

(a) Engines from the current production were to conform as far as possible to specifications (port timings, compression ratio, distance between cylinder block top face and piston crown edge at centre);

(b) The port timings were to be improved, particularly the exhaust port lead, to maximize fuel economy;

(c) The compression ratio was to be increased from the nominal value of 7.1 to 7.5 by modifying the shape of the combustion chamber;

(d) The air-fuel mixture strength delivered by the carburettor was to be improved (basic setting at idle and replacement of the present one-stage jet needle by a two-stage one).

This work started at the beginning of March 1984 and will take about six months to complete.

IV. DESIGN AND DEVELOPMENT OF A FOUR-STROKE ENGINE

One way to reduce fuel consumption in India is to use more four-stroke engines, in particular the heavier types for two- and three-wheelers. It was therefore decided to design and develop the first totally indigenous four-stroke engine. As already mentioned, the manufacturer did not give the project to ARAI so, in view of the importance of the objective for the Indian automotive industry, ARAI decided to fund the project itself. Tests showed that the advantages of the four-stroke engine, better fuel economy and durability, could be exploited by rickshaws. The project started at the beginning of November 1983 and is expected to take two-and-a-half years. The work consists of the design and further development of an engine, and the manufacture and evaluation of prototypes. The expert assisted ARAI only in its first phase, which was the design of an engine.

An analysis of power requirement showed that the engine should have a maximum power of 7.5 hp at 6,000 rpm and a maximum torque of 1.0 kgm at 3,500 -4,000 rpm. The main features of the engine selected are:

Number of cylinders	1
Displacement	150 cm^3
Bore	58 mm
Stroke	55 mm
Compression ratio	8.0
Valve mechanism	ohc, 2 valves

In order to reduce the cost of the prototype, pistons, valves and carburettors from available four-stroke engines of foreign production were used together with as many components as possible from the Indian 150-cc two-stroke engine currently in production.

Work was stopped in February because the engineer in charge of the project left the post and it was not possible to find another one. Up to that time, the following work had been completed: design concept of the engine; basic calculations (kinematics, dynamics, forces acting on the basic components); design of the combustion chamber and valve gear; drawings of the engine's cross and longitudinal sections; and selection and ordering of pistons, rings and valves. ARAI will continue the work as soon as a new engineer is employed.

V. AN ENGINE FOR MOTORIZED RICKSHAWS

In 1978, ARAI started a survey of pedal-operated and motorized rickshaws to examine the possibility of converting the pedal-operated vehicles into motorized rickshaws. It was found that the conversion of existing designs was uneconomical and impractical. On the basis of this study, a new design was developed at ARAI, and prototypes were built and tested. The tests showed that the prototypes had such defects as too much weight, insufficient stability and unsatisfactory performance. Work on improved motorized rickshaws started in 1982. Two versions with different maximum payloads have been developed.

The following aspects were taken into account in the selection of suitable engines: power requirement versus engine performance; engine durability and reliability; fuel economy; extent of required modifications; and availability.

It was found that the 100-cc engine developed at ARAI was a suitable power unit for the heavier type of rickshaw. It was adapted to rickshaw requirements and the rickshaw was adapted to accommodate this engine. Changes were made in the exhaust system of the engine to increase the maximum torque and decrease the maximum power, as a result power was reduced from 4.3 hp to 3.9 hp at crankshaft. A 50-cc indigenous two-stroke engine with a power of 1.8 hp was selected for the lighter type of rickshaw. The prototypes have been already executed and preliminary tests have shown a satisfactory performance. Comprehensive tests of both versions have still to be carried out.

VI. ASSISTANCE TO INDIAN MANUFACTURERS

The response of industry to the offer of assistance from ARAI was good. Altogether consultancy services were given to five manufacturers of two- and three-wheelers and three manufacturers of engine components. The extent of the consultancy and problems discussed with manufacturers are reported below.

Mopeds

One objective of the project was:

(a) To evaluate the improvement in engines resulting from the recommendations given to the manufacturer during the expert's mission in 1981;

(b) To assist the manufacturer to develop the engine. The main problems encountered by the manufacturer in 1981 were the poor pickup of the moped at low and medium speeds and piston seizure.

The manufacturer incorporated the measures recommended during a previous mission in 1981, and managed to remove all the defects, but in order to make the moped more competitive the following modifications were required: a power increase from 1.8 to 2.2 hp, and an economization in fuel from 65 km/h to about 80 km/l, i.e. by 20 per cent. Engine modifications already made and being tested by the manufacturer were examined and discussed. Changes in engine design were recommended with regard to the inlet port shape; inlet, transfer and exhaust port timings and exhaust port load; combustion chamber shape; and tolerances of different dimensions.

The attention of the manufacturer was drawn to carburation problems. He was advised to have the air-fuel mixture strength over the whole range of speeds and loads tested. The development of research and development facilities was discussed and equipment suggested.

One manufacturer had the following difficulties with his four-stroke engine: smoke and traces of oil in the exhaust; engine overheating; and a high fuel consumption at high speeds.

The engine design and accumulated test results were studied in detail. The manufacturer was given recommendations as to what modifications should be introduced in the engine to solve the problems and a comprehensive programme of further development work was made.

Scooters and three-wheelers

Advice was given on two-stroke engines in the following areas:

(a) Development of testing facilities;

(b) Improvement of engine durability, specifically cylinder-piston-ring assembly and requirements as to the hardness of cylinders and rings;

(c) Improving the fuel economy of scooters, particularly by thinning the mixture and increasing the compression ratio, which would be feasible on account of the new petrol with higher octane quality recently introduced in India.

The expert was in permanent contact with the manufacturer's representatives; he followed the progress of their work and made recommendations on further action.

The manufacturer carried out comprehensive tests and put into production the recommendations given during previous missions, namely, improved surface finish of the cylinder bore and a sedimentation bowl for fuel prefiltering, thus improving the average life-time of the cylinder piston-rings assembly from 15,000 km to above 20,000 km, more than 30 per cent. The manufacturer tested further modifications, namely, a more efficient air-filter and two chrome-plated rings. They improved the engine life-time to 25,000 km.

Consideration is now being given to putting these modifications into production. Apart from the project given to ARAI, the manufacturer conducted his own tests. The related problems were discussed and recommendations made for further improvements.

Motorcycles

Ways of improving the fuel economy of two-stroke engines were discussed with the manufacturer's representatives, including:

(a) Effect of the air-fuel ratio on engine performance, fuel economy and emissions; the mixture required for optimum fuel economy, and air-fuel mixture optimization;

(b) Advantages and disadvantages of different types of carburettor (sliding valve against fixed venturi), mixture adjustment at idle, its effect under load conditions, optimum idle adjustment;

(c) Effect of port timing on fuel consumption, tolerance of timings;

(d) Advantages of a reed valve compared to piston-controlled inlet timing;

(e) Sand-cast grey iron cylinder block versus an aluminium alloy cylinder block with a grey iron sleeve or chrome-plated bore;

(f) Recent developments in two-stroke engines with regard to fuel economy improvements, e.g. fluid diodes, variable exhaust port timing and exhaust pipe contraction at part load;

(g) Two-stroke engine versus four-stroke engine for application to motorcycles.

The design of the engine in current production was examined and steps for improving its fuel economy were recommended.

Carburettors

Two different carburettor companies were visited. Problems related to the improvement of carburettors with regard to fuel economy were discussed with senior engineers, including:

(a) Effect of air-fuel ratio on fuel consumption, mixture requirements for optimum fuel economy;

(b) Required and actual mixture strength in the different two-stroke engines currently in production;

(c) Parts of the operating range controlled by the various tuning factors, i.e. idle adjustment, piston valve cutaway, main jet, needle, its position and diameter;

(d) Idle adjustment and its effect;

(e) One-stage and two-stage needles;

(f) Accuracy of different carburettor components;

(g) Inspection systems;

(h) Flow-rigs for carburettor inspection and testing.

The design of various two-stroke engines in India was examined and recommendations made for economizing fuel. One of the manufacturers visited in October had already put into production the recommendations with regard to idle setting, which had resulted in reducing fuel consumption by some 5 per cent. The recommended changes of the needle shape are being executed.

Pistons

One company supplies pistons, piston rings and gudgeon pins to manufacturers of two-stroke engines. In one of the models, an occasional knocking occurred that was attributed to the inferior quality of piston assembly by the vehicle manufacturer. For want of adequate testing facilities, only limited tests could be carried out at the company. It was found that the noise was likely to be generated by the abnormal combustion process. A sequence of tests aimed at identifying the knocking was recommended to the manufacturer.

Visits to the Indian Institute of Petroleum, Dehra Dun

With the assistance of UNIDO, the Indian Institute of Petroleum (IIP) has taken up the project* "Methanol as fuel for internal combustion engines". At the request of IPP, the expert visited the Institute in August 1983 and February 1984. The object of the visits was to get to know the IIP facilities and work conducted so far and to assist in work on the use of methanol, in particular for application in small two-stroke engines. The following problems related to the use of methanol, petrol blends and neat methanol, were discussed:

(a) Effect on engine performance, fuel economy and emissions;

(b) Effect on engine durability and causes of premature wear of cylinder bore and piston rings;

(c) Lubrication and compatibility between alcohol fuels and lubricant;

(d) Resistance of materials to alcohol-containing fuels;

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*DP/IND/82/001 Application of Alternative Fuels for Internal Combustion Engines.

(e) Physico-chemical properties of fuels;

(f) Prevention of phase separation of methanol-petrol-oil blends;

(g) Extent of engine modifications;

(h) Mixture preparation in the case of neat methanol;

(i) Low-pressure fuel injection in two-stroke engines.

During the visits to IIP, the expert delivered two lectures, one on the use of alcohols in spark-ignition engines, and the other on the possibility of improvement of Indian two-stroke engine fuel economy.

The first lecture was based on work done in Poland on the utilization of both methanol and ethanol for fuelling vehicles fitted with spark ignition engines. The use of methanol was emphasized and the possibilities of using alcohols both as blends with petrol and as neat fuel were discussed.

The second lecture was based on work conducted at ARAI during the expert's previous and current assignments. The emphasis was on the cylinder block and carburation side.

Lectures

Apart from two lectures delivered at IIP at Dehra Dun, the expert read a paper entitled "Improving two-stroke engine fuel economy by optimizing carburation systems" at the Seminar on Modernization in Automotive Technology organized by ARAI and held on 16 and 17 December 1983 in Poona. The text of the paper is to be published in post-seminar proceedings.

VII. CONSULTANCY FOR ARAI

Apart from the project in which the expert was directly involved, ARAI requested his assistance with several other projects:

(a) Anechoic chamber for component testing: design, requirements, materials;

(b) Development of silencers for two-stroke engines: testing, method of calculation, equipment;

(c) A study of the characteristics of Indian driving behaviour in congested urban areas: comparison of advantages and disadvantages of European and American styles on fuel economy and emissions;

(d) Regulations of the Economic Commission for Europe (ECE) for mopeds, motor-cycles, cars and diesel engines (Regulations 15, 24, 40 and 47), equipment, testing procedures, emission limits, fuel economy tests;

(e) Carbon monoxide measurement at idle: limits, effect of idle setting, effect of operating variables;

(f) Evaluation of different vehicles with regard to their emissions and fuel economy;

(g) Indian standards in the field of internal combustion engines: revision, clarification and complement of some provisions.

VIII. TRAINING OF ARAI TECHNICAL PERSONNEL

In order to develop its facilities in the field of two- and three-wheelers, ARAI engaged 10 persons. Practically none of the new employees had any experience in the relevant fields and had to be given an intensive initial training in the theory of engines, engine building, functioning of such basic equipment as dynamo-meters, flow-meters and thermo-couples, their use for engine testing, methods of testing, types of test, recording of results, plotting of graphs and so on.

The principal training took place as on-the-job training carried out in the framework of the various tasks. The emphasis was on forming a methodological, clear-sighted approach to the problems to be solved. The technical counterpart and project engineers took part in technical discussions and consultancies held at ARAI and at certain companies for the manufacturers of engines and components.

IX. EXAMINATION OF THE POSSIBILITY OF REDUCING FUEL CONSUMPTION OF INDIAN TWO-STROKE ENGINES

An examination of the possibility of reducing the fuel consumption of Indian two-stroke engines was made on the basis of an evaluation and fuel economy tests conducted at ARAI; improvements to the engine made at ARAI; and visits to the leading manufacturers of two-stroke engines and engine components.

India has become one of the most important manufacturers of two- and three-wheelers with two-stroke engines in terms of quantity. However, design and research and development activities have not kept pace with the growth in vehicle production and population. As of 31 December 1983, some 25 main models of mopeds, scooters and motor-cycles were in production. Of those, 18 models were of European design from the 1950s and 1960s, and two were of Japanese design. Those models were acquired in the framework of collaboration with foreign companies, or copied. Only a few models were of Indian design, and these generally had a distinct foreign influence. The majority of these models have not been properly adapted to Indian operating conditions. They have been manufactured for years without any modifications because of a very high demand. In 1981, it was found that many Indian two-stroke engine manufacturers faced two problems: premature wear of the piston-rings-cylinder assembly; and poor fuel economy and high inconsistency in fuel consumption. Since then the situation has improved as far as engine durability is concerned. Steps taken by some manufacturers with regard to cylinder-block casting quality and finish, air and fuel filtration, the quality of piston and rings have resulted in an extension of the engine life-time. With a few exceptions engines have, on average, more or less satisfactory durability if account is taken of the specific operating conditions.

The improvement in the area of fuel economy is still far from satisfactory. Some companies compelled by tougher and tougher competition have started work on improving fuel economy. However, in many cases this work has been hampered by poor R and D facilities. The expert visited 10 companies manufacturing two-stroke engines and two companies manufacturing carburettors (their facilities for work on fuel economy should be similar to those of vehicle manufacturers). Only three of them had adequate facilities, the inadequacy of the rest varied from defective, improperly maintained and calibrated equipment to a complete lack of basic facilities. Moreover the basic knowledge of engine theory, design and development trends among R and D personnel was often unsatisfactory. In that connection, it seems advisable to organize a course in two-wheeler engine design, development and testing for R and D engineers. The programme should be laid down and lectures delivered by Indian and some foreign experts. It would be useful if such a course were accompanied by the issue of a textbook with a bibliography. It is suggested that all the arrangements be made by ARAI with the assistance of UNDP.

The R and D sections are often insufficiently staffed. The number of personnel involved in these activities is sometimes too low even to maintain the current production quality, let alone make any improvement.

The latest trends to improve fuel economy are that several Indian manufacturers have started collaborating with European and Japanese companies, and new, modern two-wheeler models will enter the market in the coming months, and that the Government of India has introduced a regulation exempting vehicle components from customs duty in excess of 25 per cent ad valorem on condition that the vehicles meet set requirements on fuel economy.

The requirements laid by the Government: 80 km/l for vehicles with not more than 75-cc engines; 55 km/l for vehicles with engines from 75 cc to 200 cc; and 50 km/l for vehicles with more than 200-cc engines, are moderately stringent and if met would contribute to a considerable reduction in fuel consumption. However, the applied test procedure is inadequate. Its shortcoming lies in the fact that the vehicle for fuel economy tests is supplied by the manufacturer and its conformity to the specifications in force is not checked. This makes it possible for the manufacturer to select or even to prepare an extremely good vehicle differing from the average standard. This procedure should be changed as follows:

(a) The vehicle should be chosen at random by a representative of the technical centre;

(b) Approval is granted if the measured fuel consumption is better than that specified, or refused if the measured fuel consumption is worse by more than 7 per cent from that specified;

(c) A second vehicle is chosen at random and tested if the measured fuel consumption is worse by less than 7 per cent from that specified;

(d) Approval is granted if the mean fuel consumption of both the first and second vehicle is better than that specified, or refused if the mean fuel consumption is worse by more than 3.5 per cent from that specified;

(e) A third and last vehicle is chosen at random and tested if the mean fuel consumption is worse by less than 3.5 per cent from that specified;

(f) Approval is granted if the mean fuel consumption of all three vehicles is better than that specified, and is refused in all other cases.

(A similar procedure is used in Europe for testing conformity to ECE Regulation 15 on the emission of pollutants.) This procedure takes into account the variation in fuel consumption from vehicle to vehicle, unavoidable in production, that results from inherent defects in small, particularly two-stroke, engines.

The technical details of the new models manufactured with foreign collaboration that are expected to enter the market in the coming months are not fully known. It is to be hoped that the operating conditions in India, particularly with regard to driving patterns, skill of drivers, air pollution and consumption of fuel, will be taken into account and the new models will be properly adapted to the requirements. It is expected that at least some of them will be very fuel efficient and have low emissions. The introduction of these new models will sharpen competition, particularly for mopeds and scooters, and will raise the requirements for fuel economy. To survive, some manufacturers of existing models must start improvement work as soon as possible. If their testing facilities are insufficient, the assistance of ARAI should be taken advantage of. As the work carried out at ARAI has already shown, there is scope for considerable improvement in the fuel economy of some engines. Improvements can be achieved in production and design.

As has already been mentioned, engines from current production do not often comply with the specifications. It is necessary to stress the importance of carburettor production quality for fuel economy. Some Indian models, even recent ones, have a wide variation in air-fuel mixture strength resulting in poor average fuel economy. This variation usually results from an insufficient final inspection due to poor, outdated facilities. An average improvement of at least 5 per cent could be achieved if these defects were removed.

The main means of reducing fuel consumption by engine design modification is with the carburation. As already mentioned, the tests showed that the air-fuel mixture strength is too rich particularly at idle, because of incorrect idle setting at part load and at lower speeds and full throttle due to charge back-flow in the inlet system. The first two defects can be overcome by suitable carburettor setting (jets, air bleeds, jet needles). To remove the third defect is important for fuel economy in India, where driving conditions and style are such that engines run at lower speeds than in Europe. This defect may be removed by using special delivery nozzles reducing the effect of back-flow. Such nozzles are fitted in one model of Indian carburettor. Further possibility of improvement lies in reed valves, as discussed below.

The scope for fuel economy improvement lies in compression ratio. In some 7-10 engine models this is not optimum, particularly after the petrol octane number has been considerably improved. An increase in compression ratio to the level optimum for new petrol is then advisable.

In India, two types of air filters are mainly used: oil-soaked mesh and paper. The oil-soaked filters are still in use in some vehicle models in spite of the fact that foreign collaborators gave up this design a long time ago. The problem of air filtration is neglected. The systems in use were designed in Europe or modelled after European ones. The materials used are often of an inferior quality, and the filters are not suitable for Indian conditions. The main defects are:

(a) Low dust-holding capacity resulting from insufficient specific area of filters;

(b) Low dust-retaining efficiency of some paper filters;

(c) Types of paper unsuitable for the high-humidity conditions to be found during the monsoon season (air-flow restrictions considerably increase in the case of high humidity).

The filter defects affect fuel economy because an increase in air-flow restrictions due to clogging or drenching results in mixture enrichment, and poor efficiency causes premature wear of the engine, which results in excessive fuel consumption.

The development of new air filters optimum for Indian conditions is a must for fuel economy improvement. Japanese filters, the so-called foam type, seem to be the most suitable at least as a temporary solution until an indigenous design has been developed.

The final possibility of improvement in fuel economy without major modifications consists in optimizing the exhaust system and port timings in order to achieve better trapping efficiency over the range of engine speeds and loads generally used in service, i.e. equivalent to low and medium speeds.

There are five main possibilities of reducing fuel consumption of vehicles equipped with two-stroke engines. The proper optimization of parameters or components is difficult and time consuming. Sophisticated equipment (gas analysers, test rigs, indicators), in general not in the possession of a manufacturer, is necessary. Therefore the facilities of ARAI, particularly in the area of carburation, should be developed. Moreover emphasis should be placed on the specialization of ARAI technical personnel.

Another area in which there is scope for improvement is the design of the cylinder block and reed valves. In both cases, essential modifications are required and new technological processes must be mastered. The majority of Indian two-stroke engines have a cast-iron cylinder block. This design has shortcomings arising from the manufacturing process: poor port finish and lack of precise port-timing control, which result in wide variations in power and fuel consumption. Two companies use, successfully, more sophisticated technology perfected in the 1960s in Europe: an aluminium-alloy cylinder with a chrome-plated bore.

Die-cast aluminium alloy cylinders with cast-iron sleeves is a design that is commonly used in Europe and Japan and that constitutes a logical step between a cast-iron cylinder and a plated bore, but it has not been adopted or indigenously developed in India. This design reduces the shortcomings of cast-iron blocks and therefore contributes to an improvement in overall engine performance.

Another design that has not found sufficiently wide application in two-stroke engines is a reed valve. Its advantages of higher performance and better fuel economy at lower speeds are well-known, but it is used only in two engine models.

The examination of other basic components: piston, rings, bearings, conrods, seals etc. affecting engine performance and life-time showed that their quality is in general satisfactory. Piston and ring manufacturers are well supported by their foreign collaborators and are able to develop new products.

All steps aimed at engine improvement were discussed in detail with the technical counterpart from ARAI, and ARAI technical personnel, and improvements for particular engines were shown to R and D personnel during the expert's visits to vehicle manufacturers.