UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION
Vienna International Centre, P.O. Box 300, 1400 Vienna, Austria
Tel: (+43-1) 26026-0 · www.unido.org · unido@unido.org

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APPLICATION OF ALTERNATIVE FUELS FOR INTERNAL COMBUSTION ENGINES, IIP, DEHRA DUN

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INDIA

Technical report: Improvement of design and testing of 2-stroke engines using methanol as fuel*

Prepared for the Government of India by
the United Nations Industrial Development Organization,
acting as executing agency for the United Nations Development Programme

Based on the work of Prof. O. V. Kuentscher

Backstopping officer: H. Seidel, Engineering Industries Branch

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1. Definitions and abbreviations

A	area, cross section area rectangular to the scavenging mid-stream line (in mm^2)
b.m.e.p.	brake mean effective pressure (in MPa)
b.s.f.c.	brake specific fuel consumption (in g/hwh)
BTC	bottom dead center
CE	charging efficiency
CNG	Compressed natural gas
CO	carbon monoxide
D.I.	Direct injection
DR	Delivery ratio
e.s.	engine speed (in rev/s or rpm)
ECU	Electronic Control Unit
EFI	Electronically controlled fuel injection
g	gravitational acceleration = $9.81 m/s^2$
$h_{A,B}$	water column displacement in the U-manometers for Δp_A and Δp_B, resp. (in m)
HC	Hydrocarbons
IC	Intelligent Controls Inc. Michigan
I.C.E.	Internal Combustion Engine
IHZ	Engineering University Zwickau (Ingenieur-Hochschule Zwickau)
IIP	Indian Institute of Petroleum
MON	Motor Octane Number
M12	Alternative Fuel with 12% methanol content
M90	Alternative Fuel with 90% methanol content

NG	Natural Gas
NOX	Nitrogen Oxides
ONGC	Oil & Natural Gas Commission
p_A	Dynamic pressure of the svacenging flow in cylinder head direction (in Pa)
p_B	Dynamic pressure of the scavenging flow in piston direction (in Pa)
p_d	Dynamic pressure of the scavenging flow at the test bench (in Pa)
$\overline{p}_d$	Medium dynamic pressure (in Pa)
SL	Scavenging loss
SR	Scavenging ratio
TDC	Top dead center
TE	Trapping efficiency
TE_{cal}	Calculated trapping efficiency from scavenging test bench investigations
TEL	Tetra Ethyl Lead
UNDP	United Nations Development Programme
WOT	Wide open throttle = full load
α	air excess coefficient
ΔA	Cylinder cross section area element (in mm^2)
ρ_w	water density = $10^3 kg/m^3$
ω	Charge trapping probability (in %)

2. Abstract

After analysing the Indian two-stroke gasoline engine's state-of-art in scavenging port design and full introduction techniques the required improvement steps were prepared.

A scavenging test bench was designed and installed for 50cc up to 250 cc cylinder and cylinder head scavenging investigations. First tests were initiated for the 150 cc Bajaj engine. A preliminary estimation of the transfer port design properties were made and the subsequent design alternations were proposed for a striking improvement of the in-production engines. Recommendations for the preparation of the cylinders for the test and the transfer port alternation were given. The measurement data analysis was prepared and a computer programme for the trapping efficiency calculations was passed to IIP.

The demanded activities for creating a medium pressure direct fuel injection system for small otto cycle engines were listed and discussed. This includes as well the necessary steps to be done for the development of an E F I - DI system as the steps for preliminary investigations with an mechanically controlled DI system.

Several recommendations for a knock - and "glow ignition"- free two-stroke combustion process were given including systematic investigation techniques.

Seven lectures concerning two-stroke engine design improvements on the fields of lean mixture combustion, charge stratification, knock detection and control, wear and noise reductions and alternative fuel applications including methanol fueling were presented and the papers passed to IIP.

3. Introduction

The present total Indian fuel consumption in automotive applications is characterised by the following data. The truck, bus and tractor prime movers are 100% Diesel engines. The total consumption is

- 16 million tonnes Diesel fuel per year.

The main gasoline consumption is caused by a steadily increasing amount of 2- and 3-wheeler vehicles including motor cycles, scooters, auto-rikshaws and mopeds. These are mainly propeled by two-stroke otto cycle engines. One third of the total gasoline consumption, approximately, is needed for passenger cars and other applications with four-stroke otto cycle engines. The total consumption is about

- 2 million tones gasoline per year
  - . 65% for two-stroke application (2- and 3-wheelers)
  - . 35% for four-stroke application (cars and other applications)

It is expected that the gasoline powered vehicle population and fuel consumption will increase as follows [1]:

Type of Vehicle	Number of vehicles (Millions)		Gasoline consumption (Million Tonnes)	
	1985	2000	1985	2000
Car, Four-stroke engines	0.90	2.23	2.5	3.1
2 and 3-wheeler vehicles, two-stroke engines	4.000	21.1	1.600	3.446

This is the basic background for the interest of the country:

- to maximize the share of middle distillates from the crude oil,
- to substitute a share of the truck, bus and tractor Diesel fuel consumption by methanol,
- to decrease the gasoline consumption of the two-stroke engine propelled vehicles and
- to substitute gasoline by methanol in two-stroke engines.

The raw material basis for the alternative fuel methanol in India could be the rich sources of natural gas, lignite and coal. Already today the fertilizer production is basing with a share of 7 to 8% on natural gas.

Though final decisions by the Government of India concerning the tomorrow's energy policy are not yet made there is a nee' in the country to improve the vehicle's fuel consumption at all and to learn more about the methanol application techniques in internal combustion engines (I.C.E.).

In addition to that an increasing air pollution especially in the rush hours in places can be observed. Though the air pollution problems are not obvious and due to the typical Indian driving pattern at comparitive low speeds NOX emissions seems not to be serious an increase of CO and unburned hydrocarbons (HC) emissions can be observed.

Referring to this background the revised job description of September 17, 1987 comprises the following items:

- Advise on the design aspects of fuel introduction, combustion, exhaust emission, lubrication and wear.
- Assist in development of prototype systems and devices.
- Advice in planning of experiments on research engines and on test benches to meet the project objectives.

This common and comprehensive description of the expert's duties were explained in detail by a letter dated Dec.23, 1986 of the head of the Engines Laboratory and UNDP Project Coordinator at IIP Mr. Sudhir Singhal. He envisaged particularly the participation in

- Development of an electronically controlled 2-stroke engine for methanol utilization, and
- Improvements in scavenging processes of 2-stroke engines.

4. Work Programme

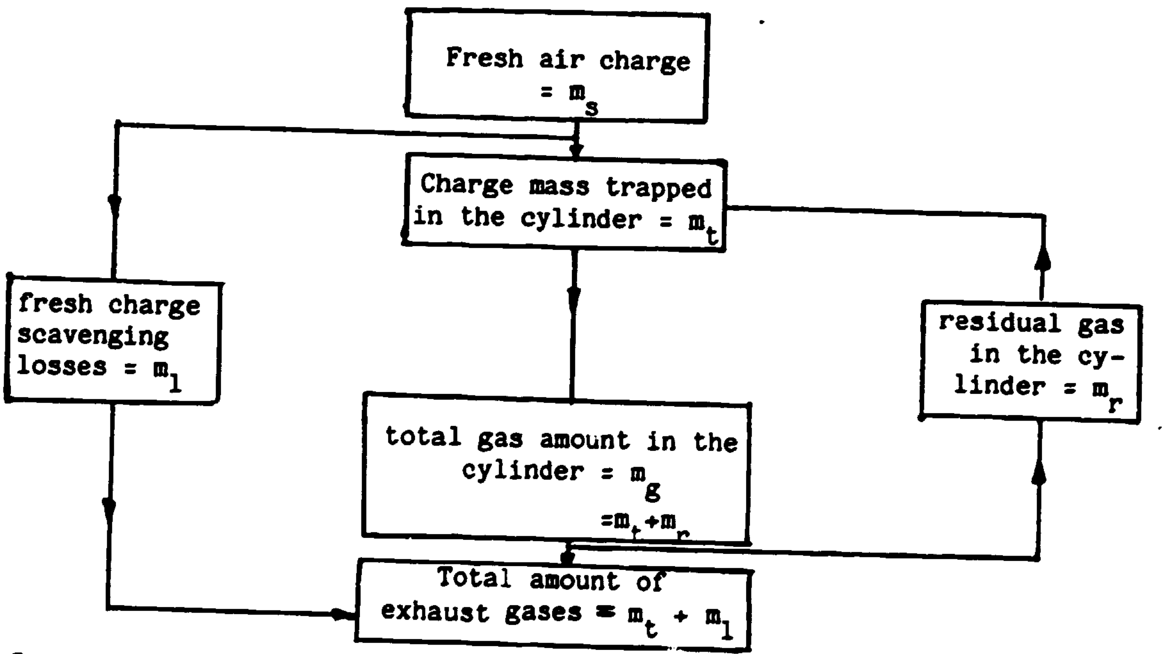
Although IIP since 1982 could achieve a certain experience in two-stroke engine techniques including methanol application by own investigations and supported by UNDP experts no serious research work was yet done to improve the scavenging techniques of the existing moped, scooter and motorcycle mass production two-stroke engines.

Special trials on engine test benches and fleet road tests were carried out to investigate the two-stroke engine behaviour with M12 and M90 fuel including lubrication improvements. Combustion studies especially concerning abnormal combustion in methanol fueled engines, charge stratification (or better "scavenging stratification" by inducted air into the transfer ports), selective exhaust gas recirculation and basic research studies on methanol ignition behaviour were prepared. A certain experience exists in thermo-fluid modelling for two-stroke engines operating on methanol and mathematical simulation of the two-stroke engine (see References [2] and [3]).

No practical experiences are existing at IIP on the field of electronically controlled fuel dosage and fuel injection application in two-stroke otto cycle engines.

4.1 Improvements of Scavenging Process in Two-Stroke Engines

A good and efficient scavenging process is one of the major elements of torque and power behaviour of the two-stroke engine. It basically influences the fuel consumption and HC emissions. The total charge mass flow through the engine is as follows:



By definition is

Delivery ratio: $DR = \frac{m_s}{m_c}$

Charging efficiency : $CE = \frac{m_t}{m_c} = DR.TE$

Trapping efficiency $TE = \frac{m_t}{m_s}$

Scavenging loss: $SL = \frac{m_l}{m_s} = 1 - \frac{CE}{DR} = 1\text{-}TE$

Scavenging ratio: $SR = \frac{m_t}{m_g} = \frac{m_t}{m_t + m_r}$

m_s = mass of fresh charge actually supplied to the engine (in kg/h).

m_t = mass of fresh charge trapped in the cylinder after scavenging (in kg/h)

m_r = mass of residual gas in the cylinder (in kg/h)

m_c = mass of fresh charge theoretically filled in the total swept volume under standard ambient conditions (in kg/h)

m_r = mass of residual gases in the cylinder (in kg/h)

m_l = $m_s - m_t$ = mass of fresh charge scavenging losses (in kg/h)

m_g = $m_t + m_r$ = total mass of combustion gas in the cylinder (in kg/h)

Trapping efficiency TE and scavenging ratio SR are scales for evaluation of scavenging process of a two-stroke engine. Under good conditions values of 0.75 to 0.85 are possible. Fig. 1 shows the Scavenging Diagramme of the two-stroke engine. It is the aim of a good scavenging process to achieve as far as possible a "displacement" scavenging. So the TE remains high and the CE is good in correspondence to supplied air mass and DR, resp. "Dilution" scavenging gives poor CE due to the decreased TE. "Short circuit" scavenging must be avoided.

Since measurement techniques for the exact determination of trapping efficiency, the scavenging loss and the scavenging ratio resp., in the real engine needs rather sophisticated equipment comparative simple scavenging test benches have been developed [4,5]. One of the recent achievement on this field is the scavenging test bench by Jaros [5]. By the introduction of a charge Trapping Probability

"ω" (see Fig.2) in a two-stroke engine cylinder, the measurement of dynamic pressure in the cylinder up-streams (see Fig.2a) and down-streams on a steady flow test bench (see also Fig. 10 of Ref.[6]) a "Trapping Efficiency" under these test bench conditions can be calculated.

Instructions for the Scavenging Pattern determination was passed by the expert to the IIP engineers Mr.J.Sharma and Mr.S.Maji (see Ref.[7], 11 pages). Since Mr.Sharma and Mr.Maji already collected first experiences in application of the scavenging pattern determination during their training at the author's department [6], it was decided to design and construct a Jaros Test Bench at IIP.

4.1.1. Selection of the Engine for the Scavenging Investigations

Though there is a need to improve the scavenging processes of the total Indian two-stroke engine population as well as of the small 50 cc moped engines as up to the 250 cc motorcycle engines in technical discussions with the responsible IIP engineers Mr.M.Abraham, Mr.J.Sharma and Mr.S.Maji has decided to start the investigations on the basis of the 150 cc scooter engines. The scooter population is the largest among the 2 wheelers in India. By special adaption plates the test bench should be made suitable to the other engine cylinders, too.

A first visual estimation of scavenging process on the basis of the cylinder and cylinder head hardware of the 150 cc Bajaj and Vijay

Scooters (drawings were not available at IIP), it was possible to draw up first preliminary conclusions:

- The scavenging system design in both engines is similar to the two-stroke engine design upto the 1950s.

- The transfer ports (two ports in both engines) are comparitive narrow. This corresponds with the most used operation range of these engines in India.

- The scavenging port design give no or only poor guidance properties to the scavenging air stream to get the desired loop scavenging process and to push the residual gases into the exhaust pipe.

  .especially the Bajaj Scooter engine cylinder has sharp bended edges in the scavenging channel causing swirls and it is to be assumed that this results in a kind of dilution or even a partly short circuit scavenging process (See Fig.1)

  .the Vijay scooter has a somewhat better scavenging port design giving partial guidance properties to the scavenging air stream.

- Since drawings of the cylinder, the upper part of crankcase and the cylinder head of the scooter engines were not available at IIP an evaluation of the production tolerances from cylinder to cylinder of the scavenging ports have not yet been made.

The expert requested to the responsible IIP engineers and Mr. Singhal to order immediately the required drawings from the engine manufacturers. Up to the writing of this report the drawings were not delivered.

- The scavenging port design seems to need a deflector type piston crown design. Though such deflector type pistons are no more in use in the above mention engines due to its unfavourable thermal properties - the scavenging port design has remained unchanged.

- The cylinder head contains a bowl shaped combustion chamber shifted to the scavenging ports side of the engine. This seemed to be necessary in combination with the former used deflector type piston. The deflector on the piston crown was shifted to the same side of the engine so that the deflector extended into the combustion combustion chamber at the top dead centre (TDC) position.

- Cylinder head and piston crown are forming a squish area on the exhaust port side of the engine at TDC. The expert likes to comment that refering to his own experiences (see Annex A: Fig.2 and References [8,10]) that only a shifted to the exhaust port side or a central positioned combustion chamber in the cylinder head gives advantages in a well designed loop scavenging process of the two-stroke engine concerning the fuel consumption and engine performance properties. So the above mentioned scooter engine cylinder head design may even retard the scavenging air flow. In additioin to that and near to TDC the squish stream is directed against the air swirl direction created by the scavenging flow in the cylinder.

Therefore the cylinder head design should be considered as well in the projected scavenging investigations. This will be helpful in another context, too (see item 4.3.1.)

Since the Bajaj scooters are the most wide spread used in India and the scavenging port design of the applied two stroke engine needs the most improvements it was decided by the expert in cooperation with the responsible IIP engineers to prepare the scavenging test bench investigation for this engine type.

4.1.2. Preparation of the scavenging Test Bench Investigations

Sketches and datas of the required steady flow scavenging test bench have been already passed from the expert's university to IIP/Engines Laboratory staff (See Ref [6] pp.5-11 and Fig.10) so it was only necessary to initiate the adaptive design and fabrication of the bench for the IIP application purposes. As responsible engineer for the scavenging test bench and investigations was assigned Mr.J. Sharma by IIP. With him the bench design was discussed and the necessary steps organized.

- An electrically driven air blower was required with a maximum flow rate of 5 m^3/min at a pressure rate in the system of 400 mm water column. It was decided to use an existing blower from a cylinder head air swirl test bench.
- An air receiver was designed and fabricated. It was decided to insert on the top of the receiver as basic plate for the cylinder mounting the cut-off upper crankcase part of the investigated engine containing also the lower portion of the scavenging ports.

- The receiver is equipped with a device for a correct piston positioning corresponding to the actual piston moving during the scavenging process.

- The receiver includes two blow-by valves for coarse and fine adjustment of the pre-pressure in the receiver. A pre-pressure of 300 mm water column should be applied.

- An air stream volume rate for the exit air passing the cylinder should be installed preferably a standardized venturi jet with an inner venturi diameter of 32 mm and an inner tube diameter of 51 mm good for flow rates from 0.05 m^3/min to 0.5 m^3/min.

- Since the investigated engine has non-rotationally symmetrical inner cylinder head contours a rotating insert containing the two required pitot tubes could not easily installed in only one or two holes.Fig.2a shows a special cylinder head design allowing a rotating indexing of the head and of the installed pilot tubes. In Fig.2a only pilot tube A is installed. But this design is only applicable for rotational symmetrical inner cylinder head contours. So it was decided to bore into a corresponding circle around the cylinder axis twelf holes in a 30 degrees angle distance. In this twelf holes the two pitot tubes A(good for the dynamic pressure measurement upstream to the cylinder head) and B (good for dynamic pressure measurement down-stream to the piston crown) are inserted. A special cylinder head was prepared equipped with a device allowing to swivel the two pitot tubes by 180° and fixing them corresponding to a prepared grid (see last page of Annex.D). Starting from a position through the cylinder axis parallel to the up and down stream scavenging flow the dynamic pressure is measured by both pitot tubes A and B in the starting plane (half maximum piston stroke) swiveling corresponding the radius points to the above mentioned grid.

- Then both pilot tubes will be inserted in the next pair of holes in the cylinder head (in steps of 30 degrees). So the dynamic pressure for the whole cylinder bore cross section area up and down stream (tube A and B) can be obtained.

- The pitot tubes are also made to move in cylinder axis direction positioned by a device on the cylinder head with a scale allowing to position the measurement bores of the tube A and B just in the same plane corresponding to the measurement area.

Note: It is recommended to start the measurements in a plane of the half maximum piston stroke. The piston should be kept 1 mm higher than bottom dead center (BTC). Often this investigation will give a good imagination of the scavenging process of an examined engine. Further measurements with different piston positions and in different stroke plane positions of the pitot tube holes can be added for the final improvement of the scavenging process.

- The bench must be equipped with a set of four U-shaped water manometers (length 1 m approx) for measuring the dynamic pressures A and B, the pre-pressure in the receiver and the difference pressure from the venturi air flow meter.

4.1.3 <u>Preparation of the Cylinders for Scavenging Investigations</u>

Since cylinder drawings were not available the investigations must start with an exact scavenging port analysis of the tested cylinder:

- As Fig.2b shows the cross section areas should be measured in layer distances of 5 mm.

- Additionally the cross section areas rectangular to the scavenging mid-stream line must be measured in the same distances (see Fig.3).

- <u>Note:</u> Normal scavenging channels have convergent cross section areas rectangular to the mid-stream line along the scavenging flow path. In addition to that sharp edges in the scavenging channels -especially in its final parts- must be avoided. Such edges are causing swirls and giving poor guidance properties to the scavenging stream into the cylinder.

- Furthermore, exact drawings have to be prepared of the cylinder liners and the piston containing all port windows. This includes the rolling out in a plane drawings of the cylinder and piston (relative to the cylinder in TDC and BTC positions). Corresponding examples of drawings were passed by the expert to he IIP engineer Mr. Sharma.

- The investigations should be started with the mass production cylinder and cylinder head including the former applied deflector type piston and now in production piston.

- After having fixed the starting conditions in the above mentioned manner systematically alterations in the scavenging channel design must be fabricated. A simple way for such alterations is to mill cut the existing scavenging ports of the investigated cylinder and replace them by special casings containing the desired shape of the transfer ports (Fig.3a). The casing material can be aluminium or/and plastics for the test bench investigations.

  Note: All these alterations must be carefully fixed in drawings for finding out the final improved port shape and recommending these alterations to the scooter manufacturer for mass production application.

4.1.4 Measurement Performance

Corresponding to the grid in Annex D the dynamic pressure p_d in the investigated cylinder is measured:

$$p_d = \frac{1}{2}(p_A - p_B) = \rho_W \, g \, (h_A - h_B)/2$$

- The dynamic pressure then is drawn into a prepared form showing a cross section through the cylinder (see Fig.4). It is to be seen that e.g. the scavenging process in Fig.4 is not yet completely optimized.

  Note: The scavenging stream must be guided by the transfer

Note: The scavenging stream must be guided by the transfer channels in such a manner that as well middle tongue formation as too much wall tongue formation will be avoided (Fig.5).

- For the calculation of the Trapping Efficiency TE_{cal} the additional grid of the probable Trapping Efficiency ω is applied (already passed to IIP Fig.2 and Ref.[6], Fig.12, Ref.[5] p. 169, Fig.2 and Computer Programme Annex D). In correspondence to the considered cross section area element ΔA with a given ω (from 0 to 100%) the medium dynamic pressure $\bar{p}_d$ in the element is calculated from the 4 neighbouring pressures p_{dij} of the element edges corresponding to the measurement grid (Annex D).

$$\bar{p}_d = \frac{\sum p_{dij}}{4}$$

Then the Trapping Efficiency is:

$$TE_{cal} = \frac{\sum_{i=1}^{1} \left(\sqrt{\bar{p}_d} \cdot \omega \cdot \Delta A\right)}{\sum_{i=1}^{1} \left(\sqrt{\bar{p}_d} \cdot \Delta A\right)}$$

This value is related to the given position of the piston and the pitot tubes. A total calculated scavenging efficiency can be calculated by adding the single TE_{cal} values and division of them by the number of measurements. Often one investigation for a piston position of 1 mm after/before BDC and a pitot tube measurement plane of half the maximum piston stroke will be meet the requirements of comparison of the different scavenging port designs.

4.2 Application of New Fuel Introduction Techniques by Electronically Controlled Fuel Dosage in Two-Stroke Engines

Referring to the Preliminary Work Programme of March 2, 1987 (see Annex A) the author presented on March 4, 1987 a lecture which was concerned with experiences at IHZ on the field of charge stratification application, fuel injection and lean burn combustion systems in small two-stroke otto cycle engines (see Annex B). In this lecture took part the majority of people responsible for or engaged in the two-stroke engine research including methanol application at IIP (see Annex C).

In connection with the lecture a comprehensive discussion and exchange of opinions with the Eng.Lab. staff/IIP was included. This also concerned the required hard-ware and soft-ware for starting fuel injection application investigations in two-stroke engines at IIP. A necessary decision referring to the programme items 2.3 (2.3.3, 2.3.4) of Annex A could not yet be made. So the discussion in a small expert discussion group was continued on 5 March 1987.

Though-depending on the hardware available for IIP in India- a final decision could not yet be made IIP the head of the engines laboratory and the UNDP project coordinator is very keen of developing a medium pressure fuel injection system. This system should be applicable for direct fuel injection into the cylinder of the two-stroke otto cycle engine with an electronic control unit(ECU). One can expect that direct injection into the cylinder of the two-stroke engine gives improved fuel economy and HC exhaust emissions [8] by avoiding or reducing fuel scavenging losses as it cannot be achieved on such a scale by low pressure injection systems only into the scavenging port or even only into the induction pipe. But low pressure electronically controlled gasoline injection systems are available on the international market (IIP started already inquiries to suppliers). The required by IIP medium pressure injection system is not available by a manufacturer. Only research prototypes existed at the Engineering University Zwickau/GDR. There is elaborated a lot of research reports, a special know-how package in handling the system and its components.

These results are mainly drawn from doctoral thesis of several post-graduates making their Ph.D.,Mr.Singhal pointed out that a special order to contract research in this field is not possible. So the author also proposed to IIP to send at least one mechanical engineer (internal combustion engines) better also an electronical engineer for graduation to IHZ with the task of development and design of the required system for scooter application.

Mr.Singhal also excluded at the moment to send one mechanical and one electronic engineer to IHZ in a long term fellowship in combination with graduation. But short term felllowships will be possible for IIP. He added that IIP intends to learn how to handle an electronically controlled medium pressure direct injection system for two-stroke applications for getting experiences and a certain feeling of its properties. They have this in mind as a mid-term alternative conception even having not hardware at the moment.

At the same time IIP will get some practical experience on the base of bench test investigations applying direct fuel injection into the two-stroke cylinder. This hardware solution should be based on mechanical Diesel injection systems being in production in India.

Taking this into account the two-stroke direct injection activities were separated into two directions:

- Collecting, development and design of software for the medium pressure electronically controlled direct injection system.
- Collecting and redesign of mechanical Diesel injection hardware from the national Indian production and adaption for methanol and gasoline injection, resp.

Note: An absolute precondition for both solutions is to install a separate lubrication system for the two stroke engine with fuel injection. Three Mikuni separate lubrication pumps are available for this purpose at IIP.

To solve the practical steps for the injection system Mr.S.Maji in cooperation with Mr.M.Abraham were assigned by IIP.

4.2.1 Direct Fuel Injection into the Cylinder by an Electronically Controlled Fuel Injection System

For the development of the required medium pressure E.F.I. system the following working steps have to be done:

4.2.1.1 To collect the necessary input data for draft calculation and design of the system the whole load and speed characteristics of the 150cc scooter engine must be available for both.

- the mass production gasoline version

  and

  the M90 test version.

The characteristics must contain generally:

- b.m.e.p. versus engine speed (e. s.) containing a grid of lines of constant power in steps of 1KW. On this grid in separate diagrams fcr the following parameters from idling upto full load.

  - b.m.e.p. versus e.s., parameter b.s.f.s.
  - b.m.e.p. versus e.s., parameter α
  - b.m.e.p. versus e.s., parameter DR

Though many investigations on the Bajaj and Vijay Scooters have been carried out at IIP engines laboratory these characteristics have not been available till the typing of this report. But they are the necessary basic values as starting conditions and for comparison purposes with the later achieved test results.

4.2.1.2 From these values for both gasoline and M90 applications a preliminary diagram should be designed for the whole load and speed range.

- b.m.e.p. versus engine speed containing as parameters in two separate diagrams.

  .inducted amount of gasoline per working cycle.
  .inducted amount of M90 fuel per working cycle (for methanol application).

4.2.1.3 Then the single components of the system must be provided or designed, calculated and manufactured. Research reports for the calculation of such a system are existing (in German) and can be ordered through IHZ (see also item 4.2).

These necessary components are (compare 1st figure in Annexure II of Annex.A):

- coarse filter
- pump (driven by the engine or electrically by a small electric motor of 0.5KW to 1KW approx.)
- fine filter
- Pressure control valve)
- constant pressure receiver) may be one unit
- pressure gauge
- wave compensator (small spring preloaded orifice blade for preventing pressure wave reflections and caviation)
- ram tube
- blocking valve
- E.C.U.
- non-return valve
- injection nozzle.

To collect and assemble the single components the author recommends the following steps:

a) A small coarse filter as they are in common use for fuel and hydraulic circuit systems should be applied.

b) The fuel pump has to be designed taking in consideration the non-lubricating properties of gasoline and methanol respectively. It must not be a gear pump (would be worn within 50h time of operation). For the required investigatio . maximum prepressures of 0.5 to 0.8 MPa should be achieveable.The calculation and design of a roller cell pump is available on special order to IHZ.

It will be decided by IIP whether either a mechanically driven pump (needs a cold start device as a simple carburettcr and gives higher losses at increased engine speeds) or an electrically driven pump should be applied. The latter one gives a simpler design if the above mentioned electric motor (12 volts) is available.

c) A small fine filter is to be applied as it is in common use for small Diesel units or hydraulic circuit systems.

d) A small pressure control valve from hydraulic circuit systems can be applied. Additionally drawings for a specially designed control valve can be ordered through IHZ.

e) The receiver (50....100cc) has the task to smooth the pressure pulsation caused by the fuel pump and the system. It should contain a pre-loaded diaphragm and can be combined with it.

f) As pressure gauge can be applied a normal mass production device with a measurement range from 0 to 1 MPa and a scale graduation of 0.01 MPa.

g) The wave compensator is a relatively simple design. But for its optimization a lot of research work was done at IHZ (Fig.6).. It prevents secondary reflection pressure waves and therefore cavitation in the system (Fig.7). Only by application of this compensator the system is working stably.

As to be seen in the 2nd figure of annexure II in annex A a constant amount of fuel from 2.5 mm^3/working cycle up to 28 mm^3/working cycle for the electronic control pulse durations from 1.5 ms up to 9 ms independent from the engine speed in the whole operation range from 10 rev/s up to 110 rev/s from (600 rpm upto 6600 rpm of a two-stroke engine) is achieved.

Since the engine characteristics corresponding to items 4.2.1.1 and 4.2.1.2 were not available up to the typing of this report a coarse calculation was made by the author. The results show that for the 150 cc engine the maximum required amount of fuel from the injection system is approximate

- 13 mm^3 gasoline/working cycle

  and

- 24 to 27 mm^3 methanol (M90...M100)/working cycle

So the system suits for the required applications.

For the test bench investigations injection tubes with an inner diameter from 2 mm up to 5 mm and a length of 0.5 m upto 1 m should be available. The ram tube length can be rolled into a coil shape (see 3rd figure of Annexure II in Annex A).

The precalculation pattern for dimensioning of the ram tubes to obtain the required inertia forces and hydraulic resistance properties is available by IHZ.

h) The main controlling component of the whole system is the solenoid controlled blocking valve (Fig.8). A lot of calculations, research and design work was done at IHZ to improve these valves to meet the requirements of 250 cc - 330 cc (swept volume per cylinder) two-stroke engines. This includes the necessary know-how of the voltage, current lift and pressure behaviour (Fig.9) including

-Coil design calculation

-magnetic force versus valve lift behaviour calculations

-application of anti-friction materials

-material composition of the blocking valve element (iron without residual magnitization against sticking).

For the 150 cc scooter engine application this know-how can be used. However the complete solenoid valve must be redesigned for this purpose by using the above mentioned proposal.

The low pressure return line to the tank from the flowing off bolting (see Fig.8, positions 12 and 13) of the solenoid valve can be a simple flexible tube(methanol resistent).

i) The non-return valve in the line from the blocking valve to the injection nozzle is a simple spring preloaded ball type design.

j) Drawings and one prototype hardware injection nozzle was passed already by the author to Mr.S. Maji/Research Engineer at IIP Engines Laboratory. Fig.10 shows a nozzle design applicable for two-stroke D.I. engines. Note that the nozzle pintle mass is extreme low. This is necessary for two-stroke gasoline injection since fuel is injected every revolution of the crankshaft and the maximum engine speed is rather high. This includes a double coiled (right--handed helix and left-handed helix) tension spring. D.I. nozzles for gasoline having a compression spring as to be seen in Fig.11 should not be applied. The pintle mass connected with the retaining ring and a socket is to high for the two-stroke engine speed range. The low pressure solenoid controlled injection nozzle (Fig.12) is not applicable to for the desired medium pressure D.I.system. The nozzle corresponding to Fig.12 can only be used for injection into the induction pipe or the transfer ports of the two-stroke engine.

Photos of suitable and non-suitable fuel spray shape formations (taken in the engines laboratory of IHZ) were discussed with Mr. M. Abraham and Mr.S. Maji. Since the cylinder swept volume of the considered 150 cc scooter engine is very small it must be strictly avoided that the fuel spray touches the cylinder wall. This would increase HC emissions, worsen b.s.f.c. and the friction of the cylinder wall. The spray must be directed either from the cylinder head into a bowl shaped piston crown or from lower cylinder parts into the combustion chamber (see Annex B,Fig.2).

For the investigations at IIP a certain number of spare injection nozzles (corresponding to Fig.10) should be available, ordered and manufactured by an injection equipment firm.

k) The applied E.C.U. should give an electric pulse width of 0 upto 10 ms,approx. Fig.13 shows a circuit scheme applicable for the required injection system. Variant a is good for the preliminary investigations of the injection system itself independent from the engine on an injection test bench. Variant b is valid for triggering from the engine. Please note that a special shape of voltage and current behaviour versus pulse timing in cooperation with the solenoid must be observed (see Fig. 9). This especially concerns the negative voltage switch off pulse preventing magnet sticking in the solenoid and giving the required steep pressure increase in the injection system. The switch off pulse has to be delivered from the final stage of the ECU.

This system must be either calculated, designed and fabricated by an IIP electronic engineer (in this way a prototype was created at IHZ) or the cooperation with a measurement equipment firm.

Note: The ECU should contain a built in correcting device. Due to the hydraulic delays in the whole system in correspondence with the control pulse duration a retarded injection beginning would occur in engine test bench investigations. This must be corrected by the ECU by advancing the control pulse beginning. This correction is even necessary for the first engine test bench investigations to achieve a stable engine run. For this purpose the pulse advance correction must contain a constant value of a few milliseconds (caused by the hydraulic delays) and in addition to that a pulse advancing in the value of the control pulse duration.

This correcting device in the experimental ECU should be designed in the manner that the amount of injected fuel (pulse duration) can be altered independent from engine speed and load remaining the injection beginning constant. These include an inpulse begin advance in the amount of the hydraulic time delay and of the pulse duration.

The final engine mapping of the engine characteristics must contain a load and speed depending control pulse beginning correction including additionally the requirements of the engine's combustion process. For the described injection system the author already published the necessary maps for a special engine (see Ref.[8], figures 16 and 15).

Additionally, it is recommended to install in the ECU also the possibility to switch of one or two pulses during the engine operation. So the engine operation can be changed from 2-stroke cycle injection (pulse each crankshaft revolution) upto a 4- or even 6- stroke mode (injection every second or third crankshaft revolution). This allows the engine to run for low power requirements of the vehicle in an increased load range of the engine characteristics by a cycle by cycle switch-off of the fuel injection. In these loads the b.s.f.c. of the engine is improved and additionally the cyclic cylinder pressure variations are smoothed by the better scavenging ratio of the engine (see item 4.1).

4.2.2 Mechanically controlled direct fuel injection

Since for the first two-stroke engine investigations a ECU and the corresponding hardware injection equipment was not available at the time first engine investigation were prepared on small Diesel injection hardware available in India.

The following steps must be done to prepare the investigations:

4.2.2.1.) The same diagrams are necessary as mentioned in items
4.2.2.2.) 4.2.1.1 and 4.2.1.2.

4.2.2.3. Referring to the intention of IIP staff to get own experiences on the field of direct fuel injection in two-stroke Otto cycle engines concerning mixture formation, nozzle design properties etc.certain steps were prepared to create a test bench equipment.

-First informations were collected by Mr.M.Abraham and Mr.S.Maji in cooperation with the author. So the Diesel injection equipment of

.the 5 HP AV-1 Kirloskar stationary Diesel engine

and

.a Lamborghini 3 wheeler Diesel engine

were taken into consideration. Due to the limited maximum speed range of these injection systems and due to the necessity to inject every revolution in a two-stroke engine it was also recommended by the author to unit the exit pipes of a two or three cylinder injection pump to one injection nozzle. This could give the desired decrease of the injection pump speed applying a reduced gear ratio by one half or two thirds.

So the characteristic curves of fuel injection pumps available in India were considered. Fig.14 shows the diagrams for the smallest K size pump. One can see that for the required maximum amount of 13 mm^3 gasoline/stroke and 24 to 27 mm^3 M90 or M100/ stroke a K pump with the smallest available plunger diameter of 5 mm should be used. This K pump is applied in the above mentioned Kirloskar engine. But the pump has no camshaft case since it is driven by a seperate cam of the engine's valve gear camshaft. This finally resulted in the preparation of an A size pump (see Fig.15) having a plunger diameter of 6 mm since a 5 mm plunger was not available at the moment. Lateron 5 mm plungers were bought and will be inserted in the pump. But this A pump was a three cylinder unit giving the possibility of the above mentioned reduction of the pump speed.

Additionally the following steps must be done.

a) Since gasoline and methanol have non-lubrication properties the former Diesel injection pump must be lubricated seperately in addition to the seperate lubrication of the investigated two-stroke engine. This can be solved either

- by seperate lubrication of the camshaft and the plunger cylinders with oil

or

-by admixture of some oil to the fuel (1% approx.) though this oil is of no use for the engine lubrication.

The seperate lubrication of the plunger with oil needs a special pump design. The plunger must contain a sealing groove. Additionally the plunger liner has sealing grooves with the corresponding hole for the fuel drainage (See Fig.16).

b) The system must be fitted (as it is normal for Diesel application) with a low pressure pump, coarse and fine filters, return line to the tank from the injection pump and the injection nozzles (if required, see next item c), and the pipes from tank to pump and pump to injection nozzle.

c) Since for the first investigations the right gasoline injection nozzles were not available at IIP a small Diesel injection nozzle was choosen for the first investigations. The nozzle contains 3 holes. Two of them must be pluged by soft wires for avoiding the fuel spray touching the cylinder wall. Here are some data of this nozzle [9]:

- max. needle lift 0.4 mm
- nozzle hole diameter 3 x 0.27 mm
- needle hole angle position (see Fig.17)

But the author insists to add that it would be most useful to apply already leakage free injection nozzles (see item 4.2.1.3.j and Fig.20). The Diesel injection nozzle needle mass will be much to high to meet the requirements of the speed range of a two stroke Otto engine. So the Kirloskar nozzles will allow only a low engine speed operation.

d) The test engine should be equipped for the first mechanical injection investigations with a simple chain drive for mounting the injection pump (simple bicycle chain will meet the requirements). Referring to the above mentioned approach for the injection pump rotational speed can be reduced by connecting the exists of the three cylinder unit.

Fig.18 shows, a photo (taken at IHZ) of a chain drive for a three cylinder two stroke car engine with mechanical injection. Fig.19 shows the applied 3AV multi-fuel injection pump. Fig. 20 shows the same injection pump applied for a high speed single cylinder two-stroke engine. The chain gearing was reduced by two thirds and the three plunger units were united into one injection pipe.

4.2.3 Redesign of the Engine for Injection Nozzle Accomodation

Two following variants of the D.I. system should be investigated by IIP.

- injection from the cylinder head against the scavenging stream in a shallow bowl shapped combustion chamber in the piston crown

  and

- injection from the lower part of the cylinder wall in the direction of scavenging stream into a combustion chamber in the cylinder head. This combustion chamber should be ball shaped and slightly shifted to the exhaust port side of the engine and surrounded by a squish area between piston crown and cylinder head.

Fig. 21 shows the injection nozzle, spark plug and injection pressure pick-up positions at a single cylinder two-stroke engine when the injection nozzle is inserted in the cylinder head. Since in this position at increased temperatures for the applied fuels (gasoline and /or methanol) vapour lock formation might occur and the increased cylinder head temperature can lead to coke deposits formation at the injector pintle one other variant must be taken into consideration.

To avoid this disadvantages the injection spray should be directed upwards into the cylinder head as to be seen in Fig.2 of Annex A.

4.2.4 Preinvestigations of the injection system

Before starting engine investigations a special test rig for both injection systems should be installed at IIP. The systems must be pretested concerning the meeting of injection fuel amount per working cycle in the whole load and speed range of the engine and for both fuels, gasoline and methanol.

The block diagram of a test rig for the medium pressure ram tuned fuel injection system with ECU was passed by the author to Mr. Maji/IIP. Additionally test result diagrams of pre-pressure and nozzle release pressure variations and their influence on the amount of fuel injected were left at IIP,too.

It is also necessary to add that exact preinvestigations must be carried out regarding the compensation of reflected waves and avoiding of cavitation (see item 4.2.1.3 e) and figures 6 and 7). The mechanical injection system can be tested as it is in common use. A injection pump test bench is already installed at IIP.

4.3 Other Studies

Since the author's experiences on the fields of two-stroke engine design and combustion, wear reduction and alternative fuel application became familiar by his lectures(see Annex B) the IIP staff engineers and scientists and ONGC employees contacted him with several questions for assessment of their work and their test results and for getting advices for the next steps to be done. The main topics of these discussions included:

- Abnormal combustion in methanol fueled two-stroke engine,
- Assessment and recommendations for the improvement of a "stratified scavenging" two-stroke test engine developed at IIP
- Automotive application of N.G.

4.3.1 Assessment of abnormal combustion in methanol fueled two-stroke engines

In the test bench investigations of the 150 cc scooter engine two types of abnormal combustion occurred.

- high load medium speed knocking
- low load high speed abnormal combustion

The first mentioned high load knocking is a well known fact and can be avoided by several means. The author will add the corresponding proposals at the end of this item. In the view of the writer the low load high speed abnormal combustion is a kind of pre-ignition. The better word for this would be "glow ignition" since it can occur before and after the normal ignition timing. This glow ignition can be caused by different hot spots in the combustion chamber. This may be

- hot gas particles
- free moving deposit particles
- hot deposits in the combustion chamber and piston crown
- other hot spots e.g. in this case the park plug electrodes.

In this context it is also important to know that the octane number of methanol cannot be improved by Tetra- Ethyl- Lead (TEL) additives.TEL does not influence the Research Octane Number (RON) but decreases the Motor Octane Number (MON), Fig. 22. The admixture of Iron-carbonyl additives increases both the RON and MON (see Ref. [11]).

Referring to the "glow ignition" the author got the experience that in four-stroke otto cycle methanol fuelled engines no combustion chamber deposits could be mentioned though with gasoline fueling such deposits exists. But in the case of the two-stroke engine due to the oil content in the fuels such deposits exists. Due to the about doubled volumetric methanol consumption rates in comparison to the gasoline fuelling 2% oil in the fuel for methanol fuelled applied in the IIP tests is too much.

A visual checking of the combustion chamber deposits by the writer showed an "unhealthy" much to black "face" (carbon deposits) in the cylinder head. A healthy two-stroke combustion chamber has a light brown colour.

For the reduction of the abnormal combustion the author recommends to IIP staff,(Dr. Pundir, Mr.M. Abraham and Mr.S. Maji) the following steps:

4.3.1.1 Reduce the oil content in the applied M90 fuel to 1%. In case of the application of an separate lubrication pump this value is only applicable for WOT conditions. Under part load conditions a further reduced oil percentage can be applied (in correspondence to the throttle valve position).

4.3.1.2 In the mass production combustion chamber of the two-stroke engine the spark plug is shifted from tne cylinder axis (see Fig.23a) into the side of the transfer port. This will give different flame path length to different portions of the space between piston crown and cylinder head. The author already mentioned in item 4.1.1 that in his experiences a combustion chamber shifted to the scavenging port side is not so advantageous. So in a first step the spark plug position should be changed into the center (see Fig.23b). The corresponding cylinder heads are available at IIP since a center bore was ·sed for pressure pick-up mounting.

4.3.1.3 In the case that step 4.3.1.2 gives not the expected improvements then a change to a centralised ball shaped combustion with a surrounding squish area is required (see Fig.23c). The maximum distance between piston crown in TDC position and squish area should be not more than 1 mm. The edges between the squish are and combustion chamber in the cylinder head must be sharp without any radius. This gives a better mixture formation.

4.3.1.4 If with the best combustion chamber design (see Fig. 23c) knocking could not yet avoided then for this variant the CR must be reduced.

4.3.1.5 For a better use of the methanol fuel properties, a slightly increased CR (with better fuel eccnomy) only can be successfully applied when spark plugs with increased heat values are used. The now in use 250 heat value spark plugs do not more meet these special requirements. To avoid glow ignition caused by over-heated spark plug electrodes higher heat values are required. IIP (Mr. Maji) got already spark plugs from the author's department with a heat value of 350. Note: The spark plugs must not have internal mass electrodes. This can cause cold start troubles. External electrode position should be preferred. Even heat values upto 400 and 450 should be included in the tests.

4.3.1.6 To explore the whole inherent advantages of methanol application a spark ignition control device as described in the 3rd lecture of the author (see Annex B and Ref.[10]) should be applied. The know-how kid can be ordered by IHZ.

4.3.2. Assessment of Engine Test Results Obtained with a Two-stroke "Strafied Scavenging" System

After reading the 3rd leacutre (see Annex B and Ref.[10] the expert was contacted by Mr. Mukesh Saxena for assessment of his test results with the above mentioned two-stroke engine. The system was developed at IIP in cooperation with the UNDP expert Dr. Radzimirski. The engine inducts via reed valves air into the transfer ports and fuel-air-mixture via the inlet port.

The author was requested to assess the achieved b.s.f.c. recuc-tions with the new technique. So the curves of b.s.f.c. versus air excess coefficient for both the mass production engine and the new system were submitted.

The investigations were carried out with a constant ignition timing as it is in use for the mass production engine. This was done since IIP got the experience that two-stroke engines are not so sensitive to ignition timing. In the author's view this statement is only valid for the application of comparitive rich mixtures in the to-days mass production two-stroke engine. A modern lean burn [8] or high compression technique [10] including the developed by IIP "scavenging stratification" needs an optimized ignition timing. Only this way in combination with comparatively lean mixture fueling gives the full advantages in reduced fuel consumption, CO and HC emissions reductions. So the writer recommends to Mr. Saxena to repeat the tests with optimum ignition timing (for minimum b.s.f.c.). So further full consumption reductions are expected.

A general recommendation can be drawn from this fact for further engine investigations at IIP.

- Every engine optimization without optimum ignition timing is useless. Every test point must include optimum ignition timing (for Diesel engines-optimum injection timing).
- Part load investigations for comparison purposes with constant throttle opening positions are of no use. Such investigations must be carried out at a constant torque (constant b.m.e.p.) for minimum b.s.f.c. The throttle position is of no interest under part load conditions.

4.3.3 Industrial Consultations

The expert was contacted at IIP by Mr. C. Khosla/Consultant (Marketing) at ONGC New Delhi. The problem submitted was as follows that India has an excess of natural gas (NG). Only a share of it is used in a fertilizer plant, in power houses instead of coal, for electricity boards and in small industries as furnace oil replacement.

Referring to C.N.G. application the expert gave the following recommendations:

- All possibilities of local CNG application or the connection with pipelines a spread application should be firstly exhausted as follows:
  - . for bigger or even smaller power stations as generator sets, since India is still far away of complete electric power supply (frequent power cuts)
  - . furnace, small industrial and even cooking applications.
- Since C.N.G. gives not such an advantageous energy density for the fuel including the tank as a liquid fuel automotive CNG application reduces the pay-load (heavy tanks or bottles) and operation range. It therefore should not be applied in passenger cars. Limited truck applications are imagineable e.g. with two stages of gas compression:
  - . For a limited number of NG pipeline maintenance trucks gas can be filled directly from the pipeline with a pressure of 2 MPa. This needs comparative huge tanks. But the total pay-load of these trucks is not used normally. So the pressure tank would not disturb.

. In a destricted area with a limited operation range of the considered vehicles a compressor filling station (20 MPa) should be installed. Such vehicles could be

+ delivery trucks for urban supply (no long distance trucks)
+ tractors and trucks of big farms
+ town buses

etc.

The expert could not give any recommendation for the construction of a small moveable methanol plant for fuel production at small gas fields with a limited capacity. Though not being a chemical processing engineer in the writer's view a methanol plant with high investment costs can only be founded as a centralised factory using either gas or coal as raw material.

4.3.4. Advice for an Fuel Injection Control System

The expert was consulted by Dr. Pundir/IIP concerning the order of an IC Fuel Injection Development System. This system is expected suitable for all in production low pressure electronically controlled fuel injectors. Since this equipment might not meet the requirements for the solenoid control of a medium pressure injection system-required by IIP for direct in cylinder fuel injection- the writer could not support this intention at the moment.

If additionally, IIP wishes to deal with low pressure manifold or transfer port E F I the system should be ordered by a supplier delivering both the fuel injection development system and the injectors.

5. Training of IIP Scientists and Engineers

The training of IIP staff mainly took place on the job basis in correspondence to the items 4.1; 4.2; 4.3 of this final report. This included daily or many consultations a week with the responsible staff men in the office and in the laboratory.

Additionally the writer presented lessons weekly (see Annex B). These lessons includedcomprehensive discussionS related to the topics and other touching technical fields.

Also the days after the presentation of the papers the expert was contacted many times by IIP staff members wishing an assessment of their own test results and asking for advices of further improvements of the work and the investigated research topic. So e.g. the reading of the papers 1,2,3 (see Annex B) caused a lot of advice searching by IIP and the corresponding recommendations by the writer (see items 4.3.1 and 4.3.2).

Furthermore, the paper No.4 (see Annex B) caused again the searching of advices by Mr. Mukesh Gupta. The author presented in his 4th paper a new brass coating technique- applicable also for cast iron two-stroke cylinder liners- reducing the cylinder wear by one-half approximately.

Since IIP measured an increased cylinder wear above the exhaust port portion of the scooter two-stroke engine cast iron cylinder liners and with methanol application an increased top piston ring wear, the author could recommend to IIP to order the brass coating of about fifteen cylinder liners and/or to order the know-how technique at IHZ for IIP internal applications.

Furthermore, the author was requested by IIP staff to leave one copy of the presented papers at IIP. Additionally it was proposed to submit the papers 2;4;5;6;7- especially prepared for the UNDP mission of the author at IIP and not yet published- to the X National Conference on I.C.Engines and Combustion on Dec.11-19, 1987 at Prototype Dev. & Training Centre, Rajkot, India.

So, to IIP was passed one copy of each paper (Annex B) and the above mentioned ones submitted to the Rajkot Conference.

6. Recommendations

The most recommendations are already included in the activities report i.e. in items 4.1; 4.2; 4.3; 5.4.

6.1 Since the required Scavenging Test Bench will be readily installed upto the expert's departure the following tests must be carried out:

6.1.1 Measurement of the scavenging pattern (see item 4.1) and calculation of the Trapping Efficiencies of the now in mass production two-stroke cylinder liners.

6.1.2 Exact drawings of the existing scavenging ports must be designed. Additionally the author recommends to fabricate reversed block plastic models of the two-stroke cylinders including transfer ports for all modifications investigated in the future.

6.1.3 In systematic steps the scavenging port design must be improved. This has to be done by milling off the existing ports. On the milled-off area special casings are to be attached containing the desired scavenging port alterations.

6.1.4 Every alteration must be correctly stored in drawings.

6.1.5 The best scavenging port design than might be produced in hardware cylinder castings. These altered cylinders finally have to be tested on an engine test bench.

Note: A new carburettor setting can be expected as an necessary succession. It is of low use to investigate engine alterations without an subsequent air excess coefficient and ignition timing optimization.

6.1.6 The cooperation between IIP and the scooter engine producers must be strikingly improved. So the manufacturer must be more interested in increasing the products quality in this case especially for fuel consumption and emissions reductions. This is also important for getting changed prototypes for test bench investigations.

6.1.7 The safety instructions must be strictly observed.
- correct and shielded wiring
- no uncovered rotation shafts (e.g. of the blower)

6.2 For getting first experiences in two-stroke D.I. application it was decided (see item 4.2 and 4.2.2) to start with a mechanically driven system, so the following must be done:

6.2.1 To carry out all the steps carefully mentioned in item 4.2.2.

6.2.2 Also in this case the author likes to add that a closer cooperation with an Indian Injection Equipment producer, e.g. Mico Bosch, Bangalore, is urgently required. This concerns mainly the prototype fabrication of leakage free pintle type injection nozzles (see Fig. 10). Only these nozzles have the low pintle mass to meet the otto two-stroke engine requirements (injection every revolution).

6.3 Referring to the desired by IIP long term alternative of medium pressure EFI applications for collecting, development and design of the software and subsequently the hardware the following steps should be observed.

6.3.1 In the author's view the most necessary steps mentioned in item 4.2.1.3 can be done by IIP, expecially the software design. Manufacturing is to be done in IIP workshop and in cooperation with the specialized industry in India (e.g. the injectors, item 4.2.1.3 j and 6.2.2 resp.).

6.3.2 Some components cannot be prepared only in India on the basis of the existing knowledge and facilities. These are:

- fuel pump calculation and design (item 4.2.1.3 b) including pressure control
- Solenoid blocking valve calculation, design and tuning with the ram pipes (item 4.2.1.3 h)
- calculation and design of the ECU (item 4.2.1.3 g).

So the author recommends to use the above mentioned possibilities of short term scholarships by IIP with IHZ. This is necessary to become familiar with the calculation, know-how and test techniques for atleast one mechanical and one electronic engineer and atleast twice terms (each of about 4 to 6 months) within two years. This could be combined with postgraduate further training (M.Sc.) or/and correspondence graduation (Ph.D.).

6.4 Since the UNDP Methanol Application Project will finish by July 1987 it is necessary to mention that except methanol application- the Indian 2- and 3- wheeler two-stroke engine design needs a further improvement. This concerns mainly the already mentioned

- Scavenging process and in steps of increasing difficulty special designs as e.g.
- lean burn combustion
- scavenging stratification
- high compression with automatically controlled optimized anti-knock ignition timing etc. upto the more sophisticated
- EFI-DI technique.

The author likes to make a final recommendation concerning the fuel consumption reductions in this case especially for the huge 2- and 3- wheeler two-stroke engine propelled vehicle population. The fuel consumption can be reduced by different technical means, e.g. by a more effective scavenging process upto the sophisticated EFI-DI technique.

But it is necessary to add that a high percentage of fuel in India is consumed by the caotic traffic conditions especially in places. This includes as well indisciplinary driver, bike-rider- as pedestrian behaviour. So the traffic often results in short distance acceleration and deceleration patterns including useless and risky overtaking.

So it is recommended to the government of India to flank the engineering means for vehicle fuel consumption reduction by

- better traffic organization (e.g. separation of the pedestrians from the vehicle traffic, one way system etc.)

- traffic education of the population by several means (School, TV, Newspapers etc.)
- traffic education of the drivers for an economic driving mode (before getting the driving licence and further training).

7. Advancement of Test Bench Design and Construction

The scavenging test bench installation could be realized within the experts duty period at IIP. It is expected that upto his departure first scavenging tests with the in production cylinders and cylinder heads will be performed. Not yet so far advanced is the design analysis of the existing transfer ports. Since drawings are not available this must be carefully done (see e.g. Figures 2b and 3) by the responsible staff engineer at IIP. From this scavenging patterns the conclusions for transfer port design alterations must be drawn.

The progress in the much more comprehensive task of the installation of the D.I. system was moderate. This could not directly be influenced by the author since the responsible engineer at the same time was concerned with the abnormal combustion investigations (see item 4.3.1).

So upto the writing of this report only some hardware for a mechanical injection system from Indian production could be choosen, ordered and collected (different small injection pumps and injectors). The required alterations in the pump equipment (smaller plunger diameters) were carried out and the hardware bought. The necessary injector alterations (see items 6.2.2 and 4.2.2) were discussed with the responsible engineer.

Referring to the compiling of the required software for the EFI-DI system the informations and drawings were passed to the assigned mechanical engineer.

But the writer insists to add that also simultaneously an electronic engineer must be included by IIP in this task (see also item 1.5.3.2).

8. Conclusions

As a result of the expert's mission and in close cooperation with the responsible IIP staff members a Scavenging Test Bench for small two-stroke could be installed. This gives the test facility in combination with an evaluation scheme and calculation programme fopr the achieved trapping efficiency to improve strikingly the scavenging process quality of the in production two-stroke engines. This should be done in closer cooperation with the manufacturers as it is now common practice.

The necessary software steps to be done for the development of an EFI-DI system have been discussed and included in this report. Some certain components (see 6.3.2) require a further training for both an IIP mechanical and electronical engineer at IHZ.

Finally the author likes to express many thanks to Mr. S. Singhal Head of the Engines Laboratory and the IIP scientists, engineers

- listed in Annex C- for the good cooperation and the numerious requests making use of the knowledge on the field of two-stroke engines and methanol application collected at Engineering University Zwickau/GDR.

Prof. O.V. Kuentscher
M.Sc. Ph.D. D.Sc.

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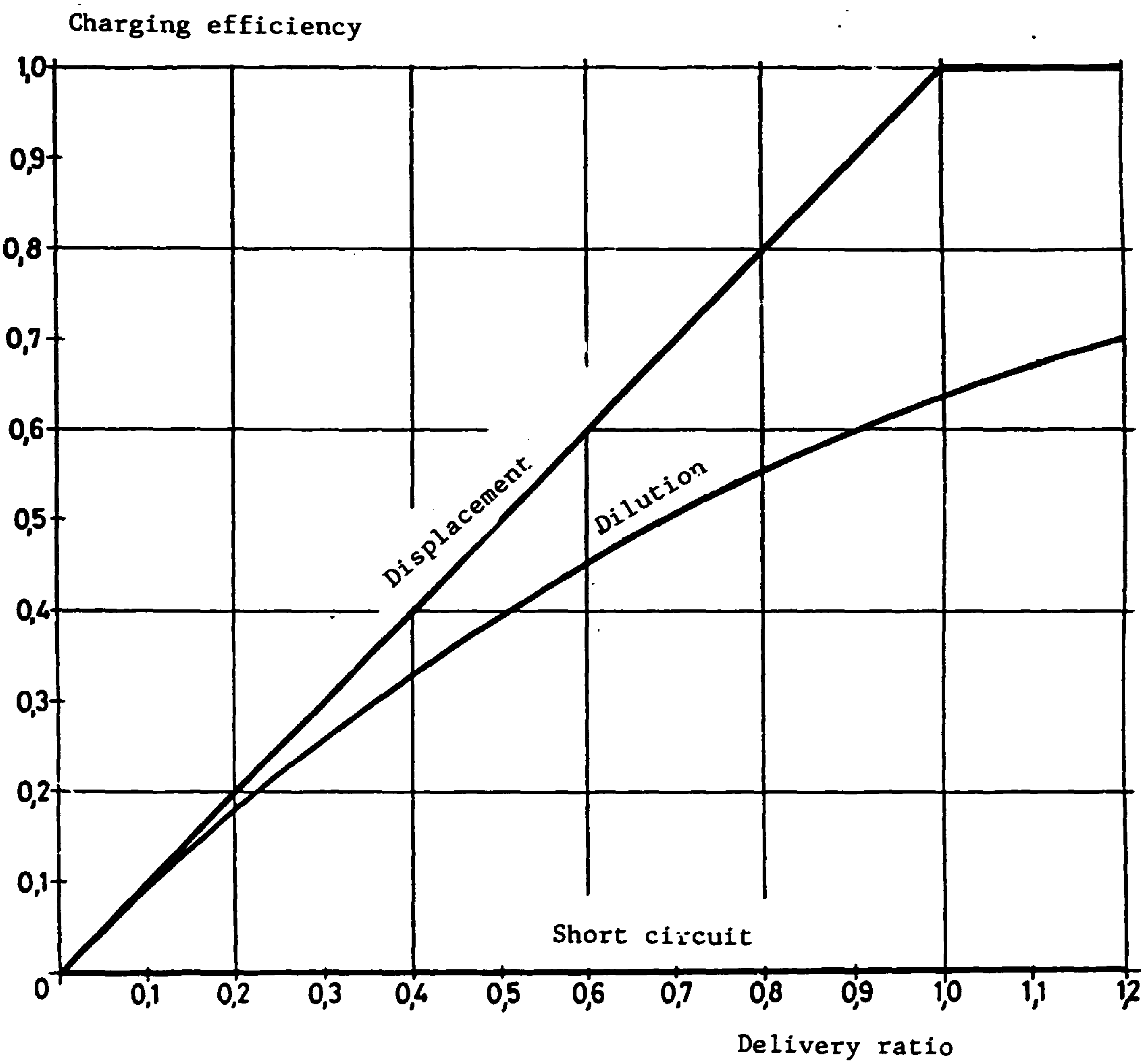


Fig. 1: Scavenging Diagramme of the two-stroke engine

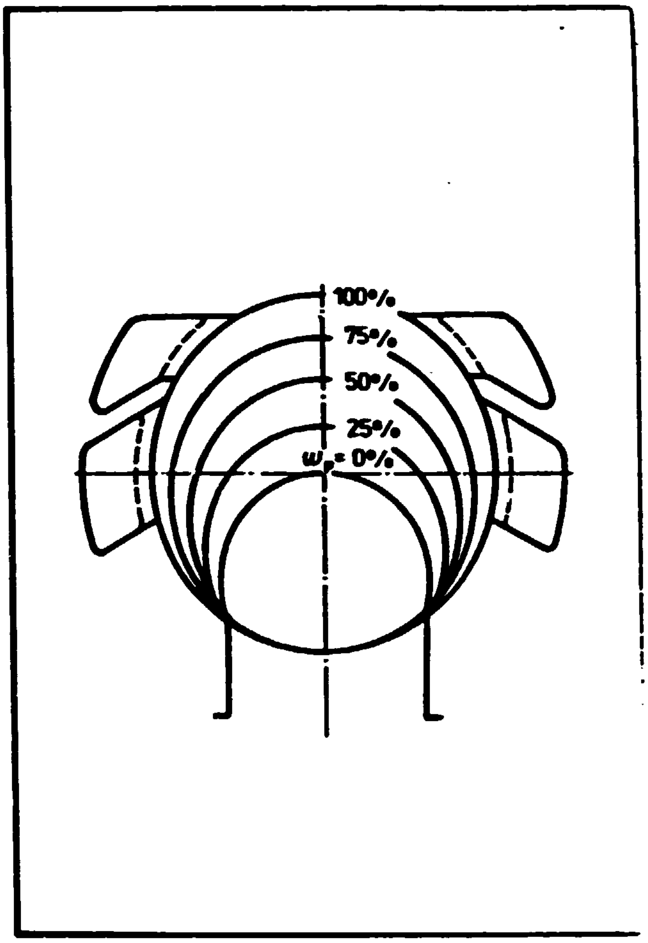


Fig. 2

Charge trapping probability
in a plane rectangular to the
cylinder axis at half
maximum piston stroke

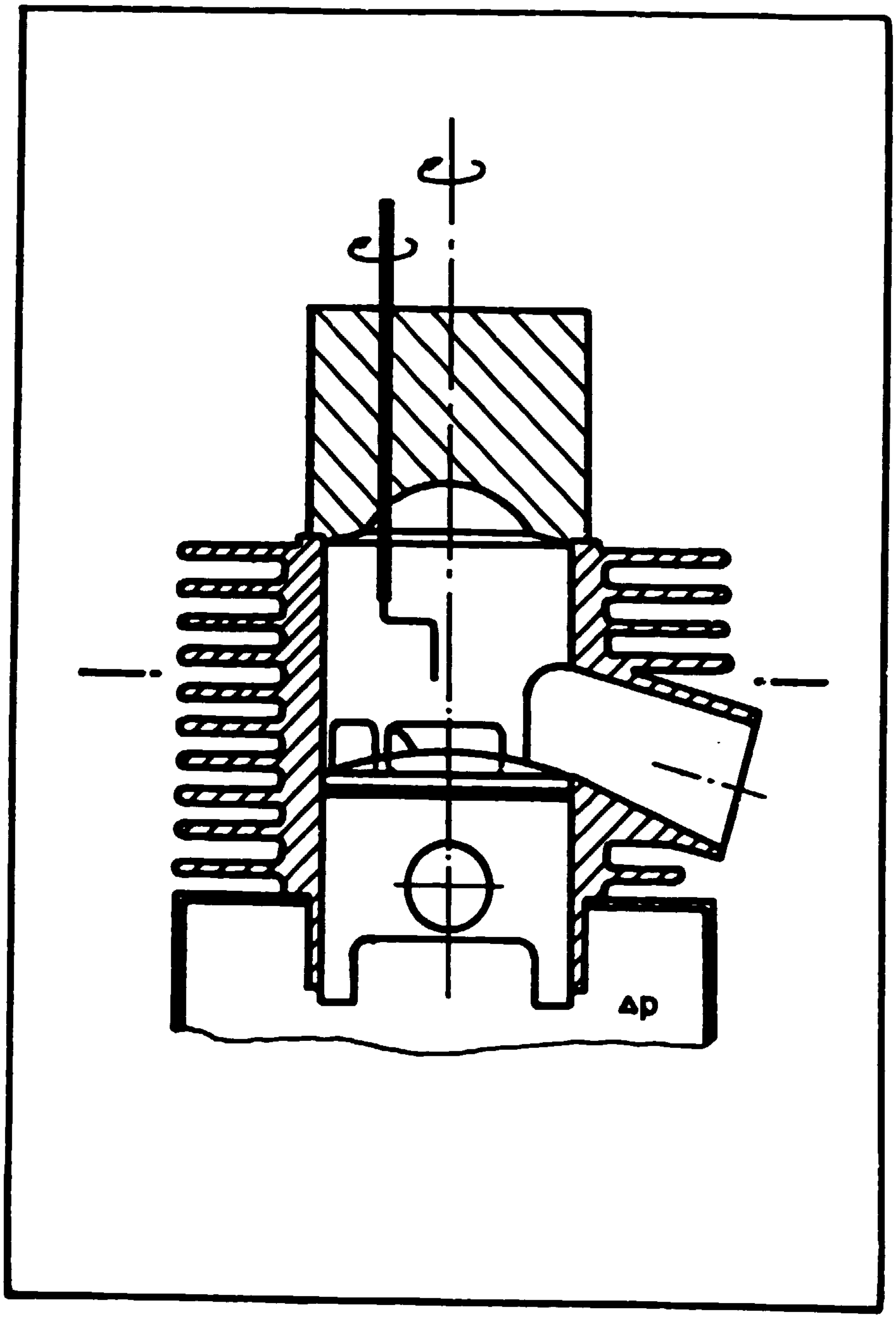
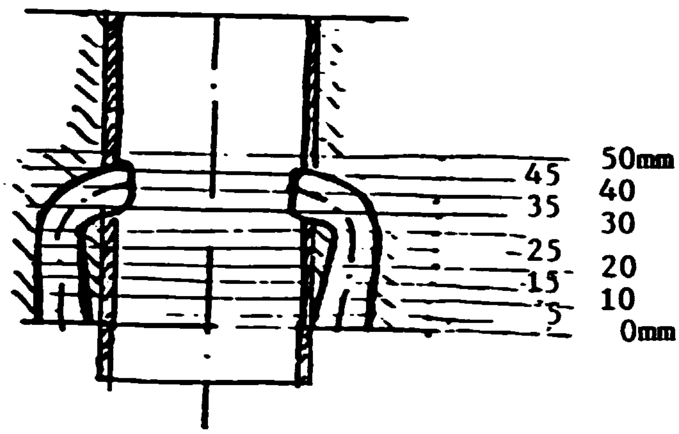


Fig. 2a

Cylinder and cylinder head installations on the scavenging test bench

- symetrical cylinder head is made to swivel
- installed pilot tube A is made to swivel.



Cross section area
Measurements should be done in steps between the layers of 5 mm

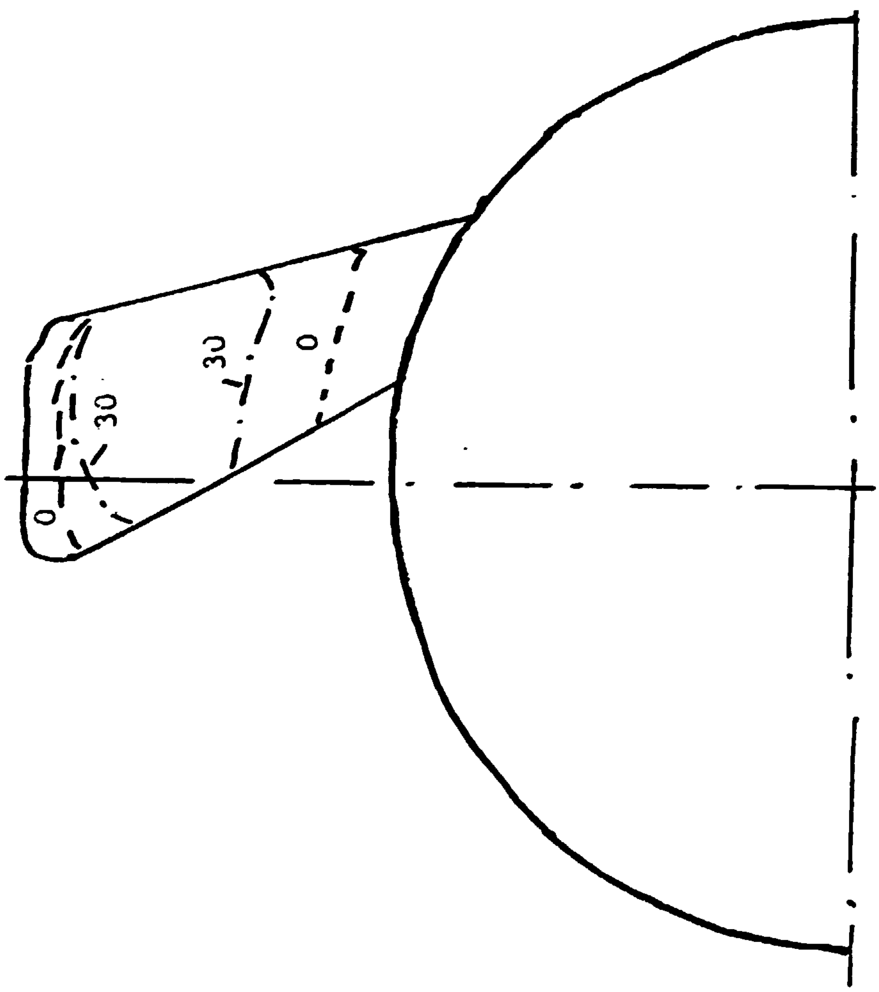


Fig. 2b: Scavenging part cross section area analysis

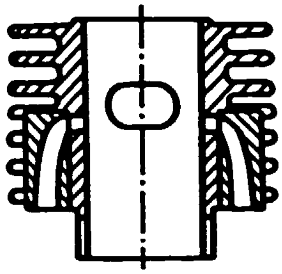


Fig. 3a Scavenging port casings for test bench investigations

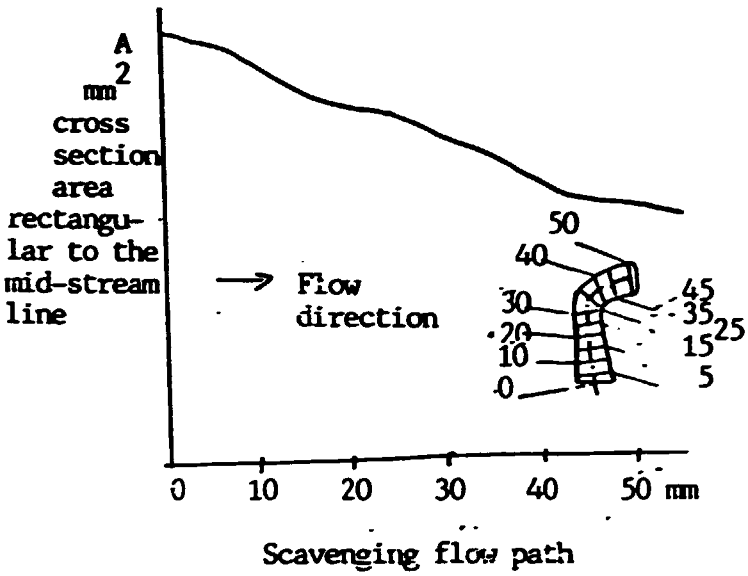


Fig. 3 Scavenging flow cross section area analysis rectangular to the mid-stream line

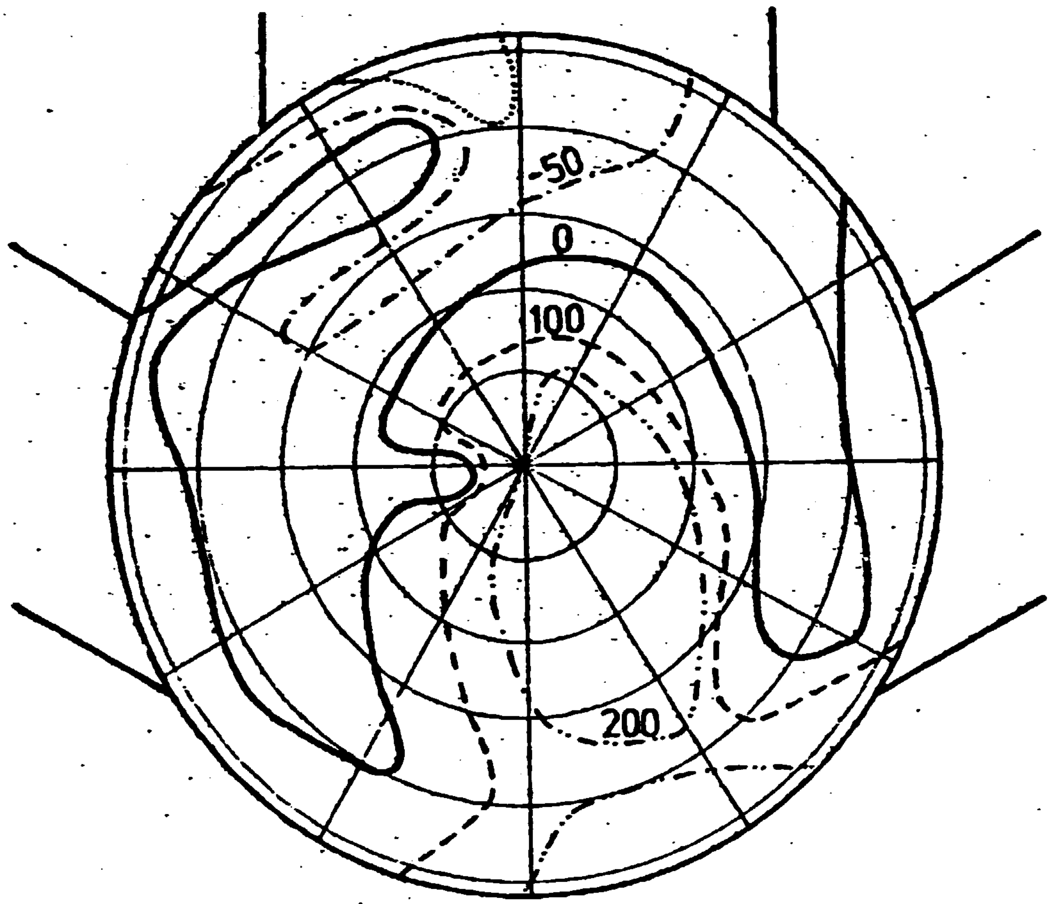


Fig. 4

Scavenging Pattern

. Engine: 150 cc
. Measurement plane: one half of maximum piston stroke
. Piston position : 5 mm after BTC
. Trapping efficiency: 44.85%

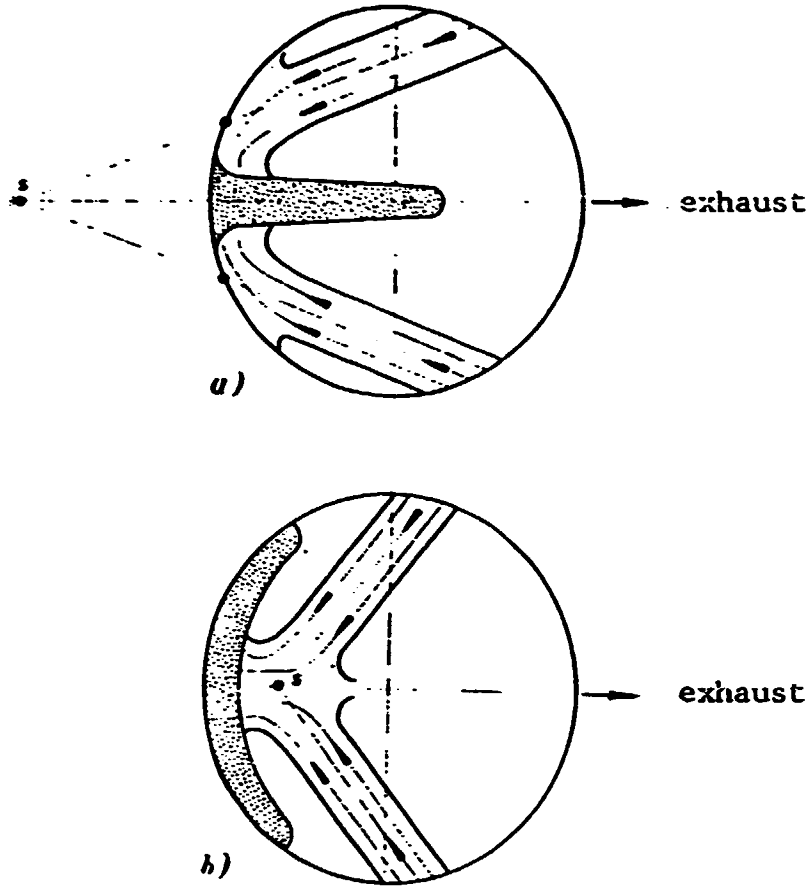
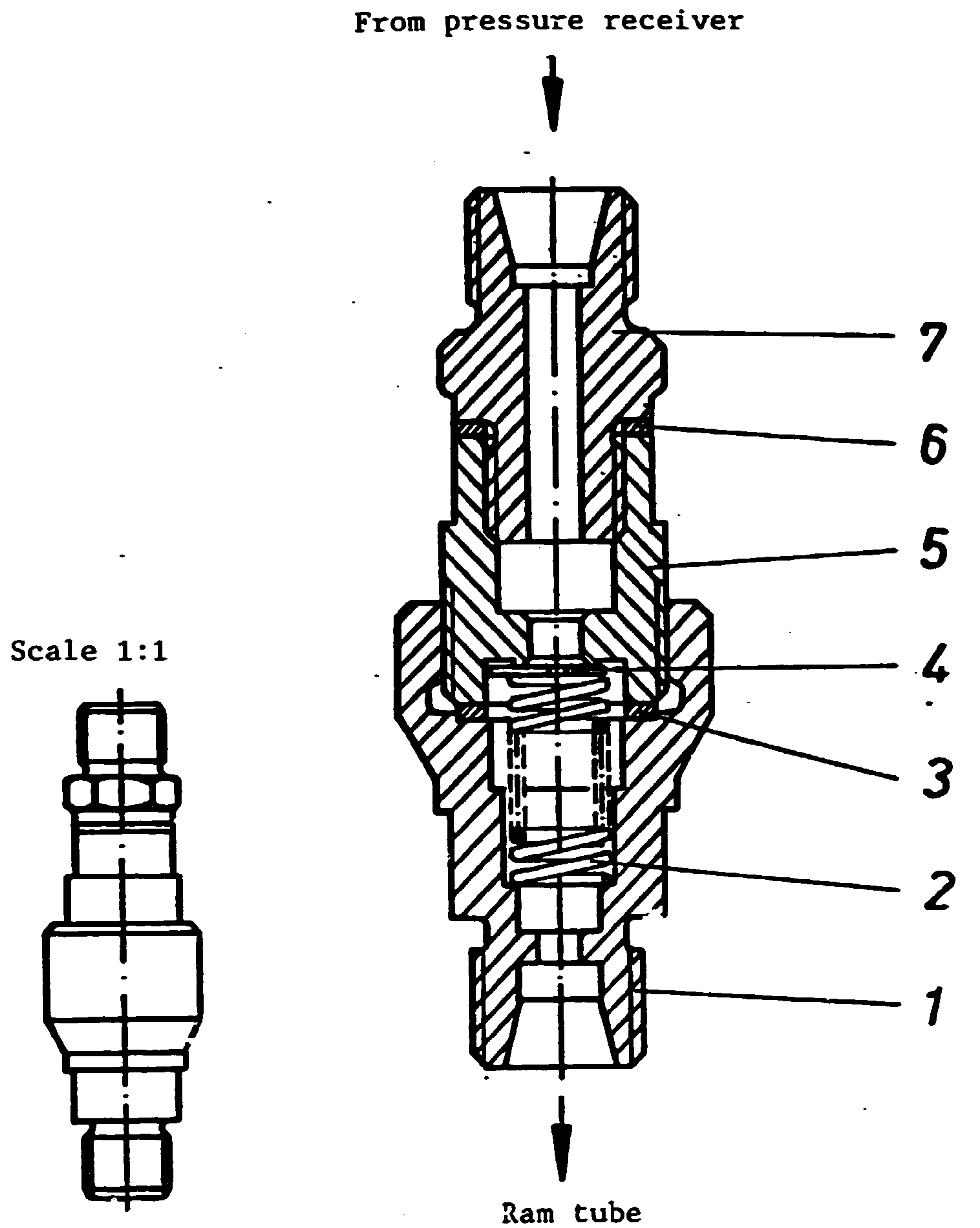


Fig. 5 Typical faults in scavenging port design

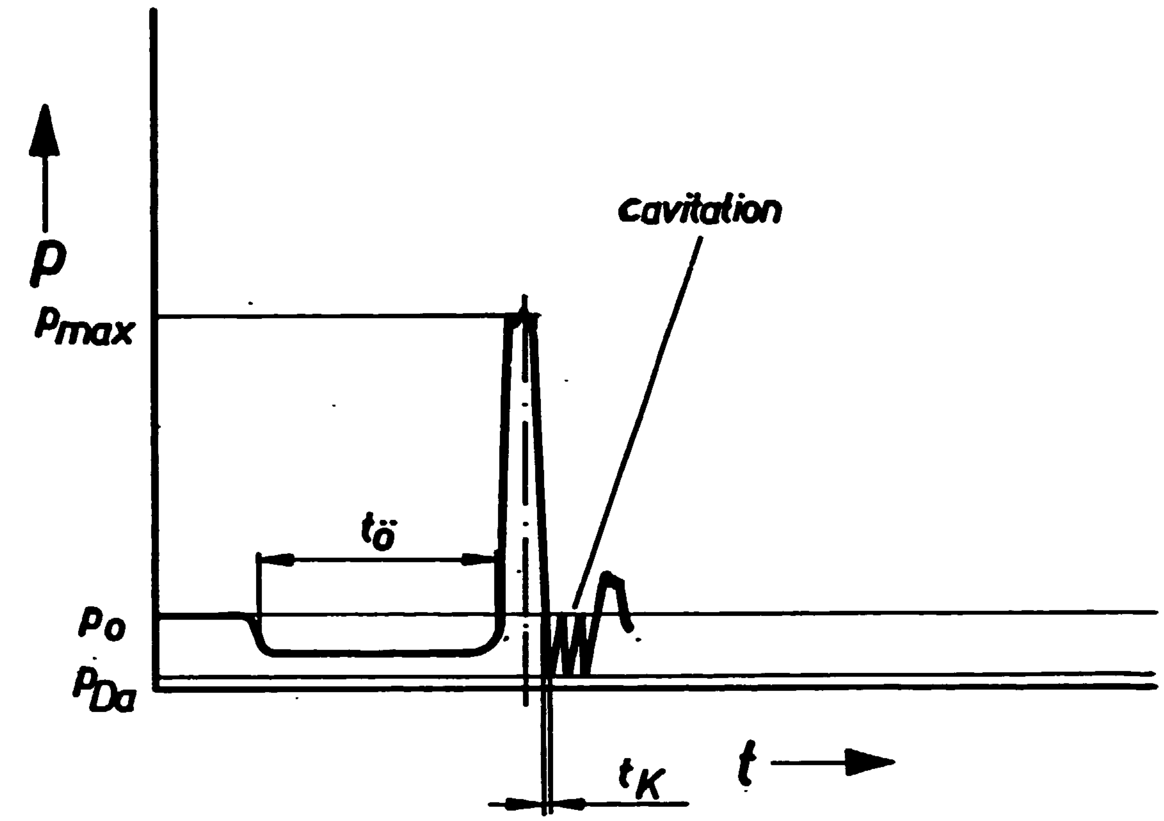
a) Middle tongue

b) Wall tongue



1 Lower casing
2 Spring
3 Sealing
4 Valve flap (plastics, top view triangular)
5 Upper casing
6 Washer
7 Fitting

Fig 6. Wave compensator



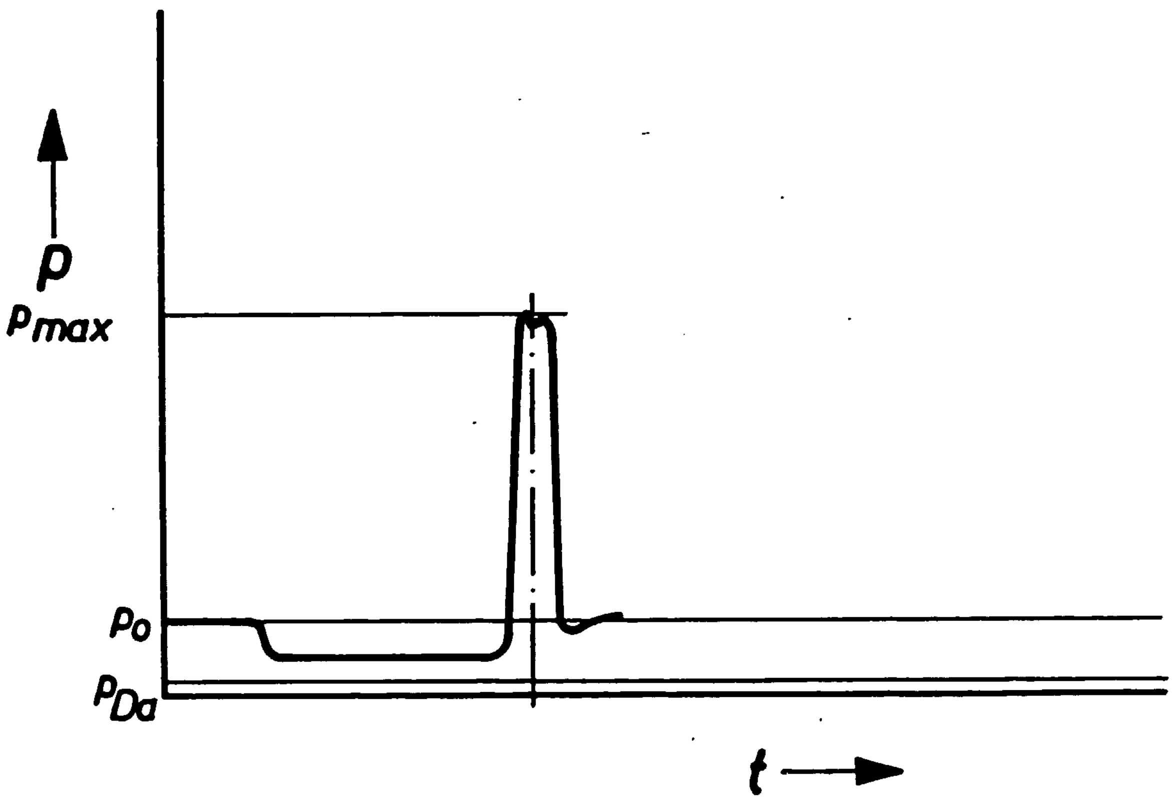


Fig. 7 Pressure histories before the blocking valve

a) without wave compensator

b) required pressure history (with wave compensator)

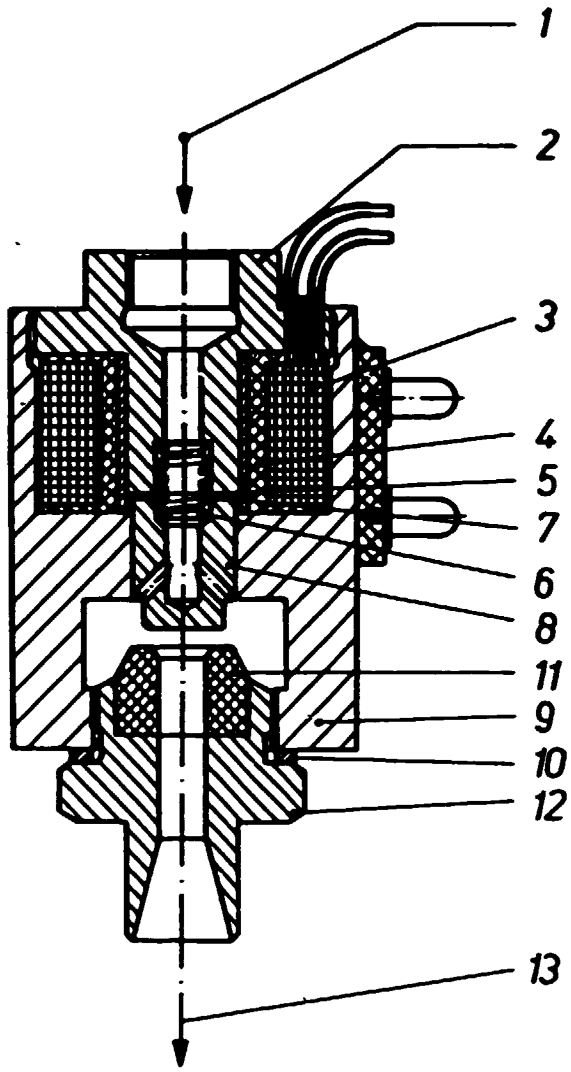


Fig. 8 Electromagnetically operated blocking valve

1 inflow
2 coil holder
3 winding
4 coil body
5 tube
6 spring
7 washer
8 blocking valve
9 case
10 sealing
11 sealing insert
12 bolting
13 flowing off

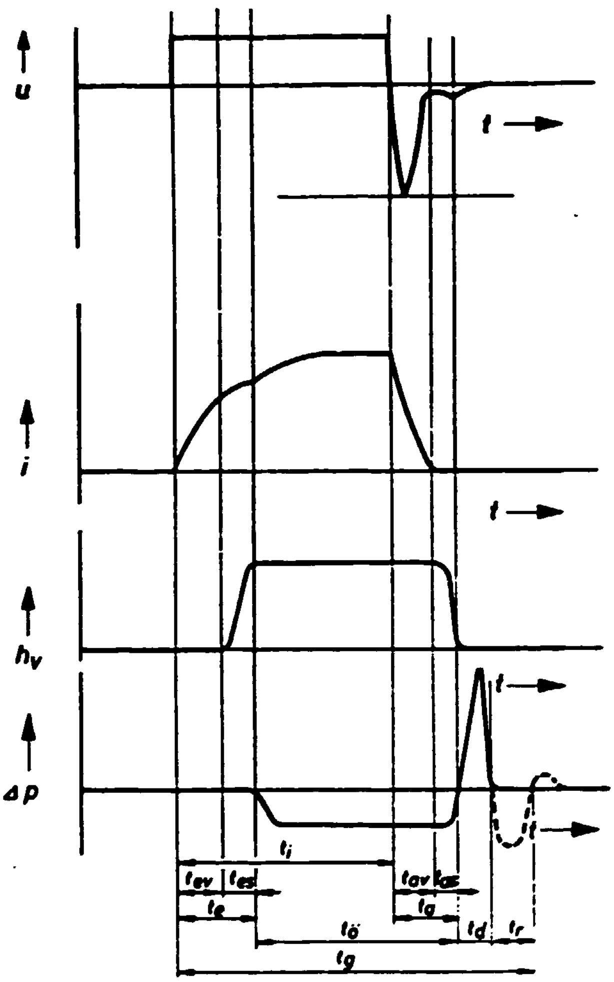


Fig. 9 Voltage–current–stroke–pressure behaviour in front of the injection nozzle

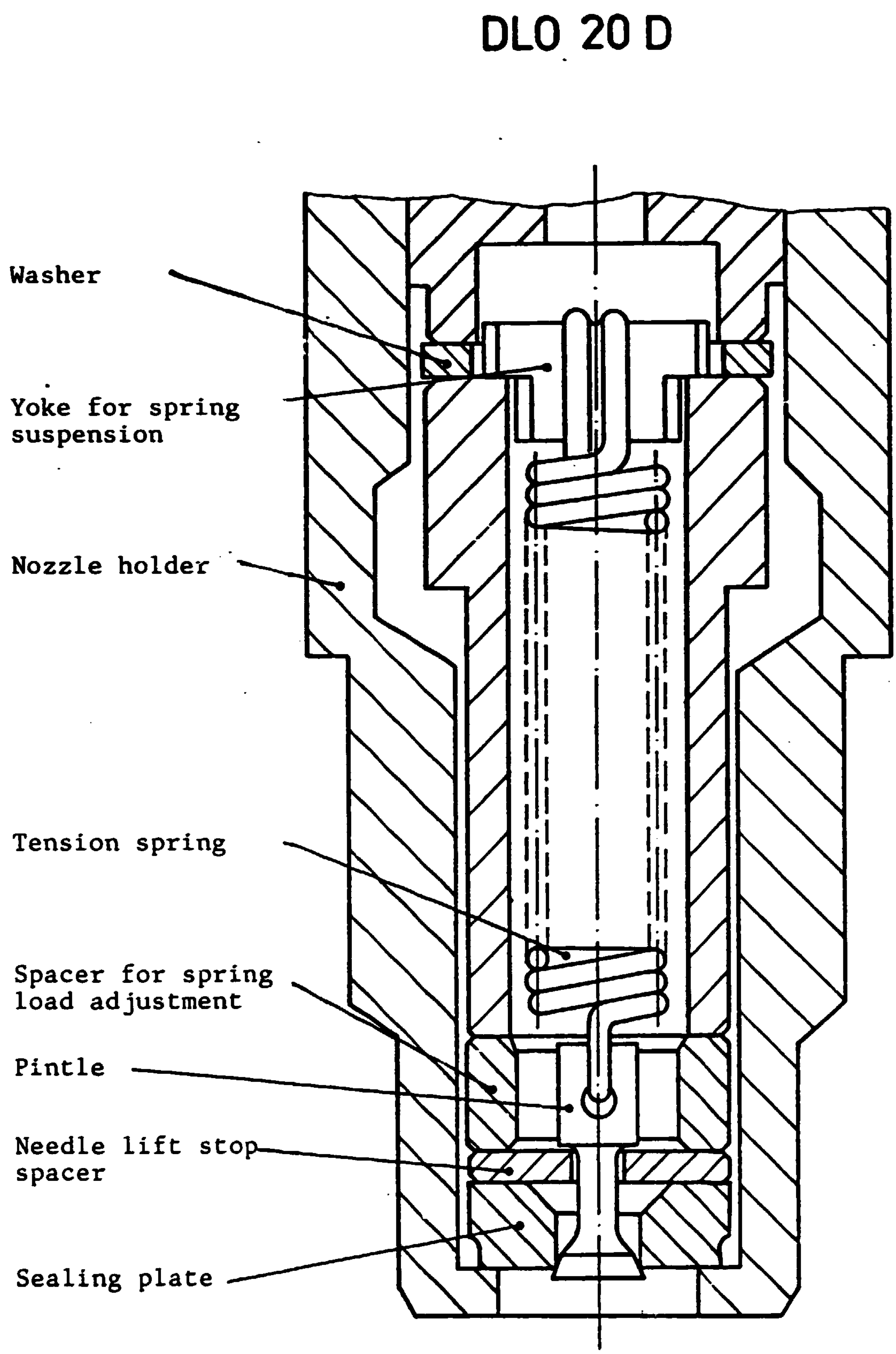


Fig. 10 Injection nozzle DLO 20D for gasoline direct injection

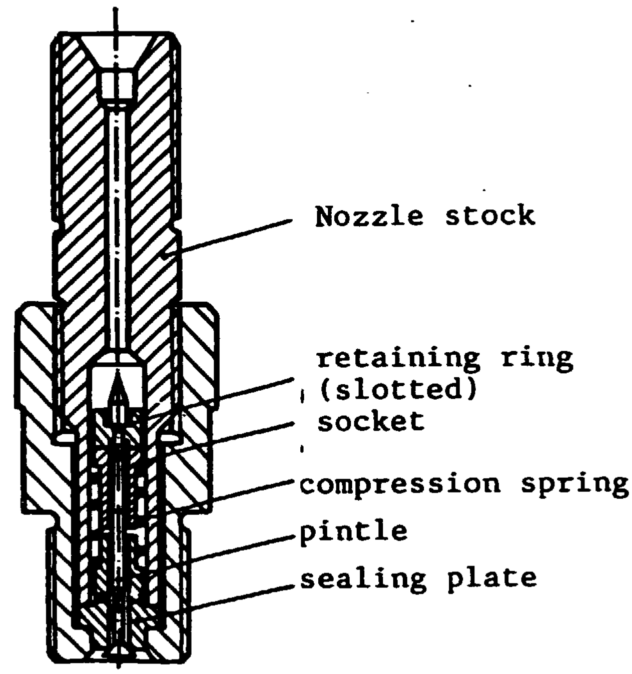


Fig. 11 Injection nozzle for gasoline direct injection

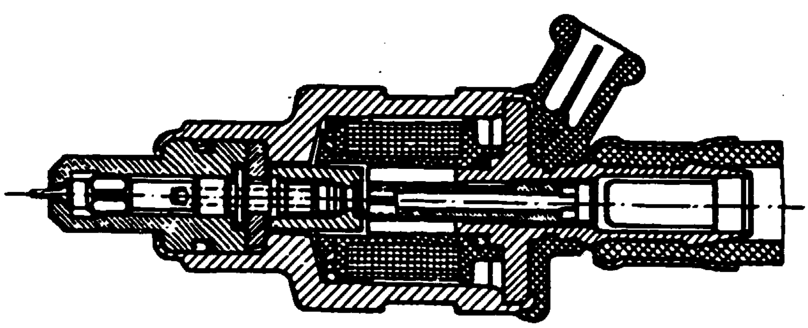
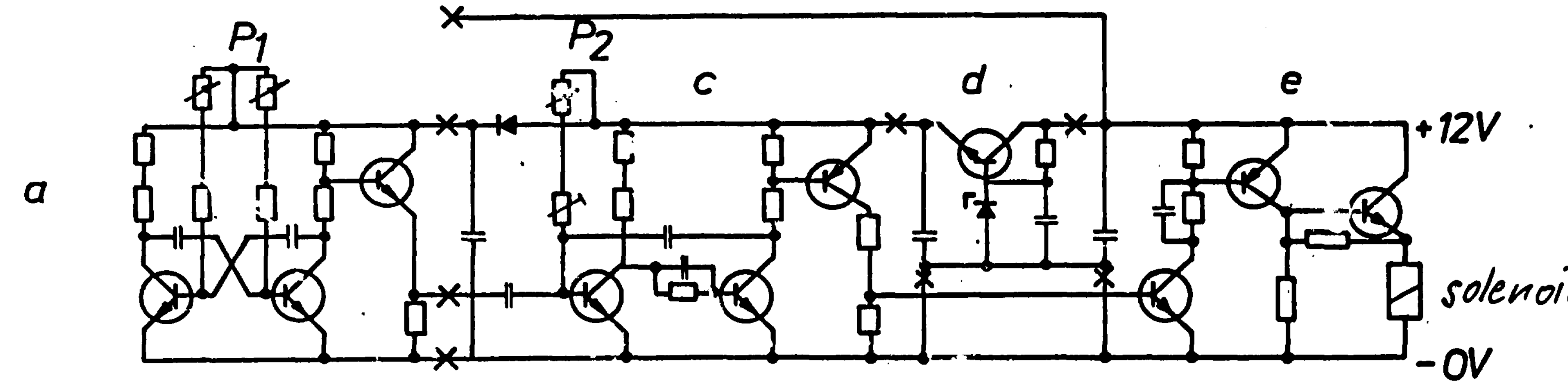
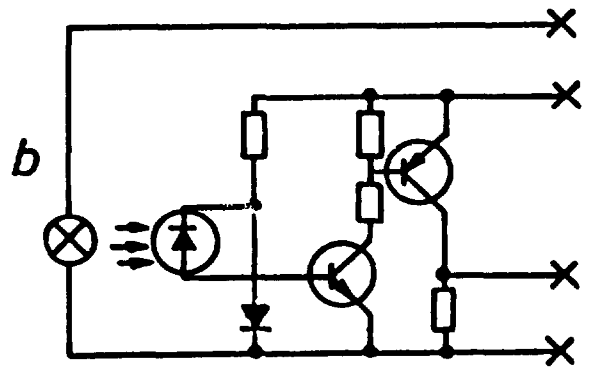


Fig. 12 Low pressure solenoid controlled injection nozzle





a with multivibrator circuit for the prototype system

b with photo cell triggered by the engine speed

c dosage circuit

d voltage stabilizc

e ᶜ:nal stage

Fig. 13 Circuit scheme of the power CU

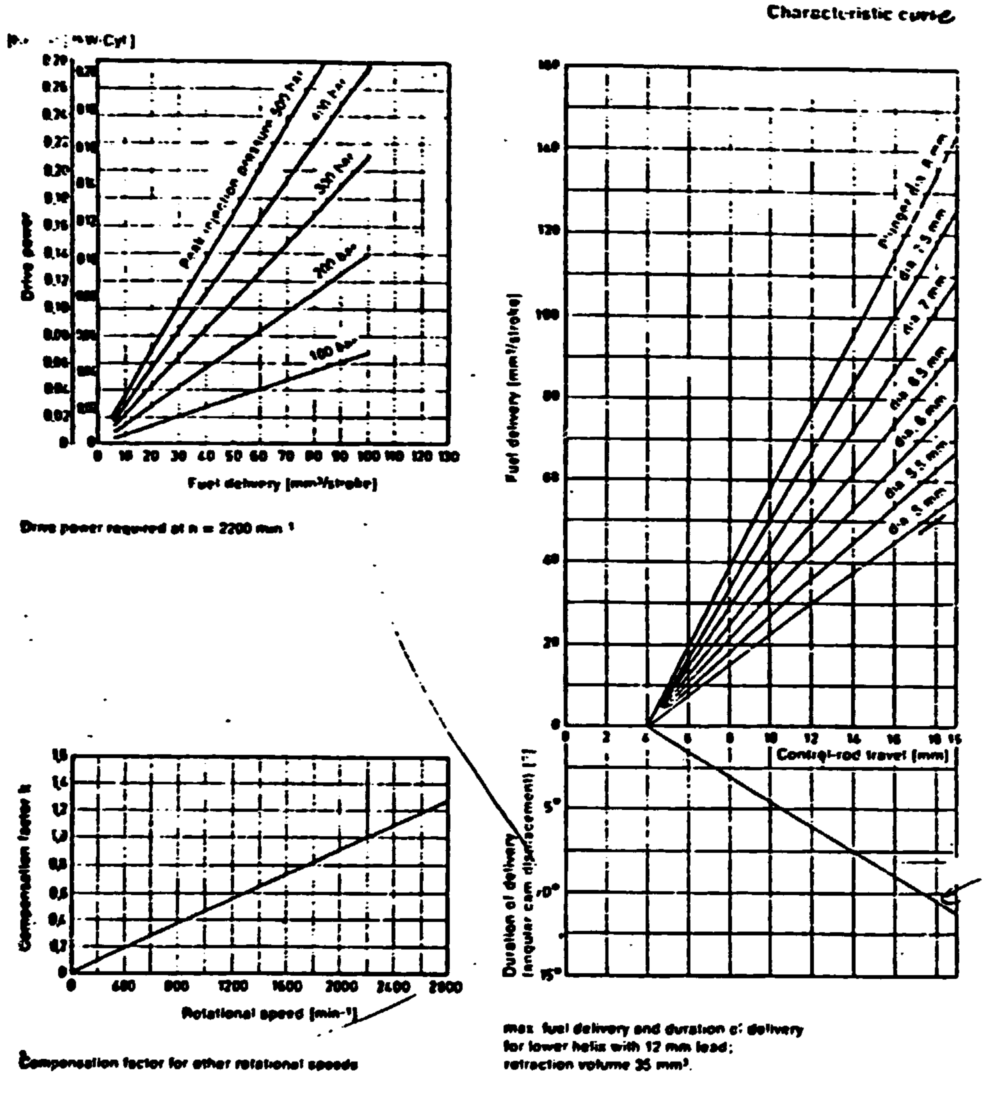


Fig. 14 Fuel injection pump - Size K

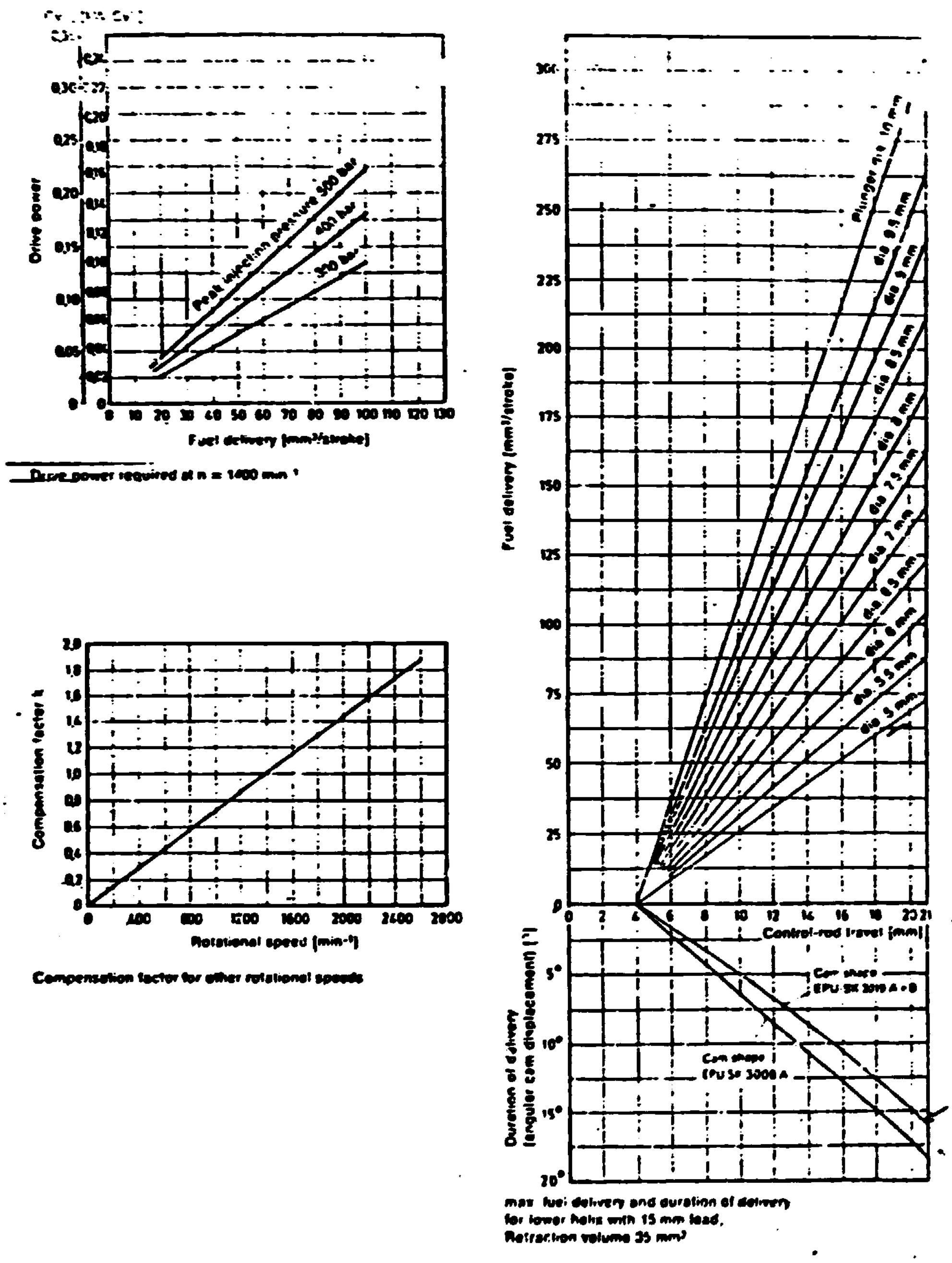


Fig. 15 Fuel injection pump Size A

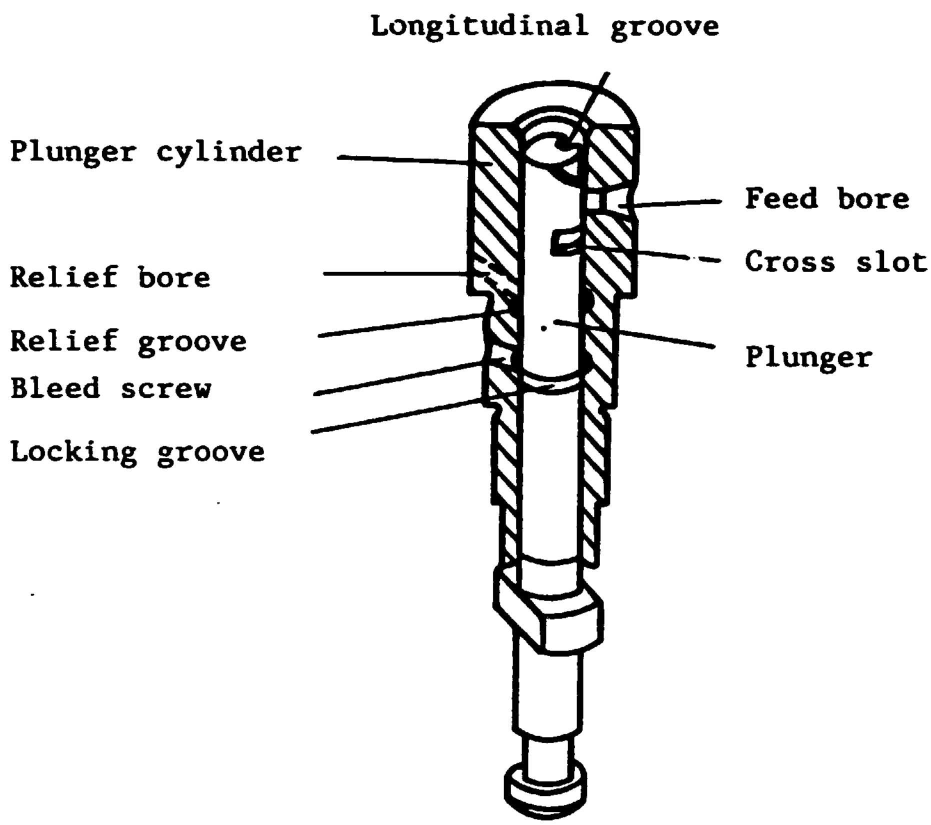


Fig. 16 Plunger element with oil lock

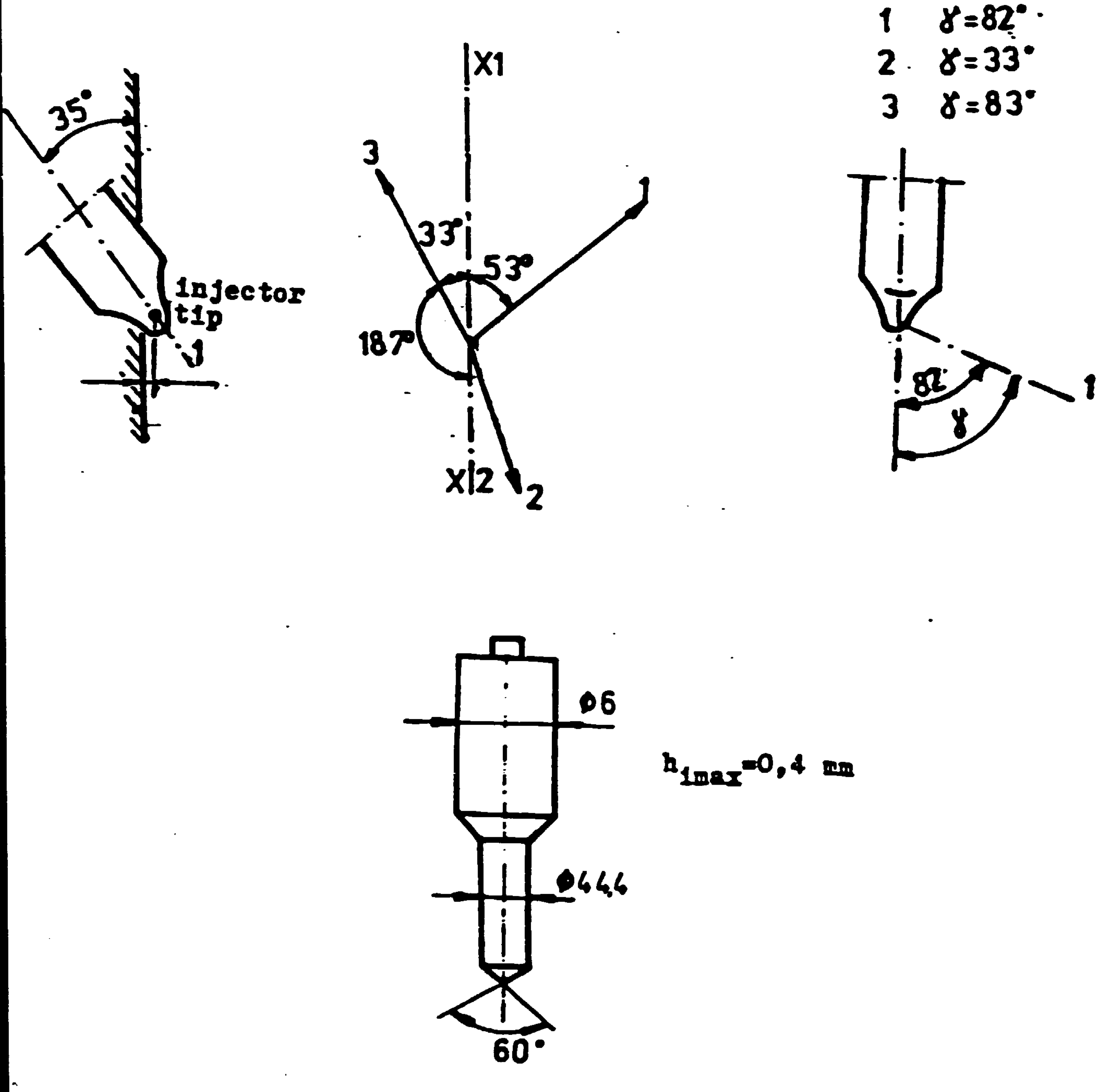


Fig. 17 Nozzle hole arrangement for Kirloskar engine

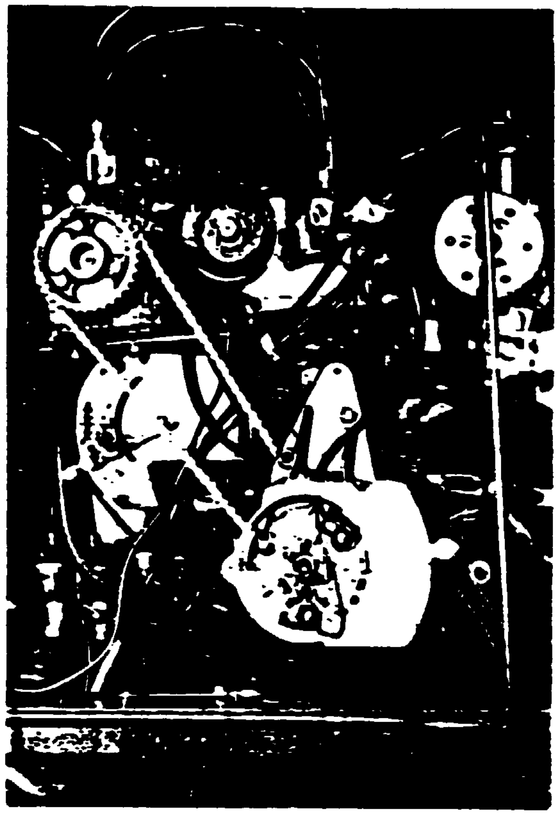


Fig. 18 Mechanical driven injection pump with a three cylinder two-stroke engine

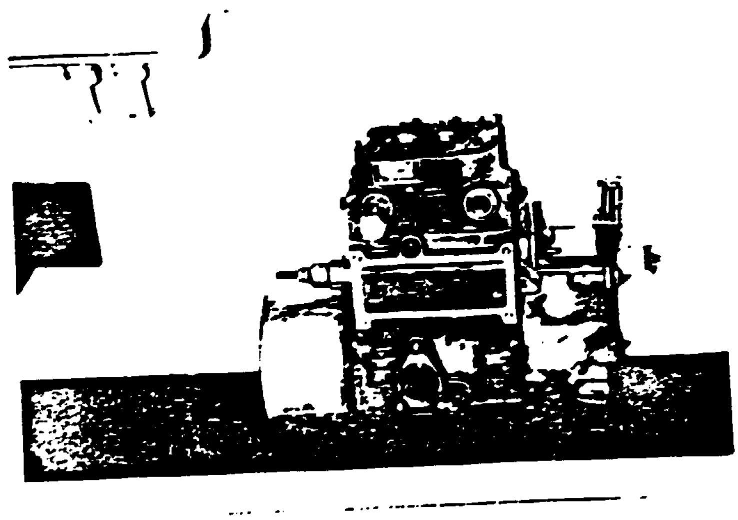


Fig. 19 3 AV multi-fuel injection pump

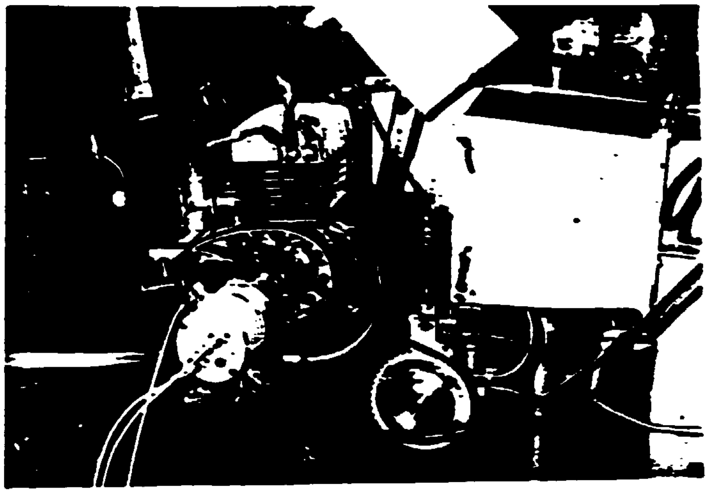


Fig. 20 Reduced chain gearing for application of a three cylinder injection pump to a single cylinder two-stroke engine

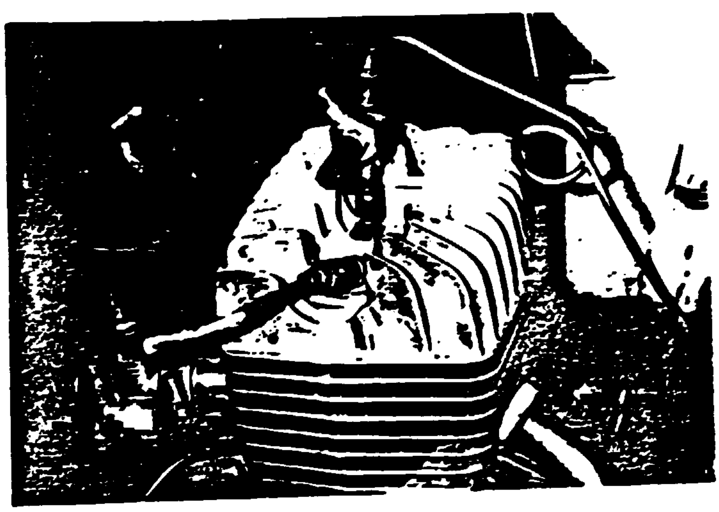


Fig. 21 Injection nozzle , spark plug and injection pressure pick-up arrangement at a single cylinder two-stroke engine

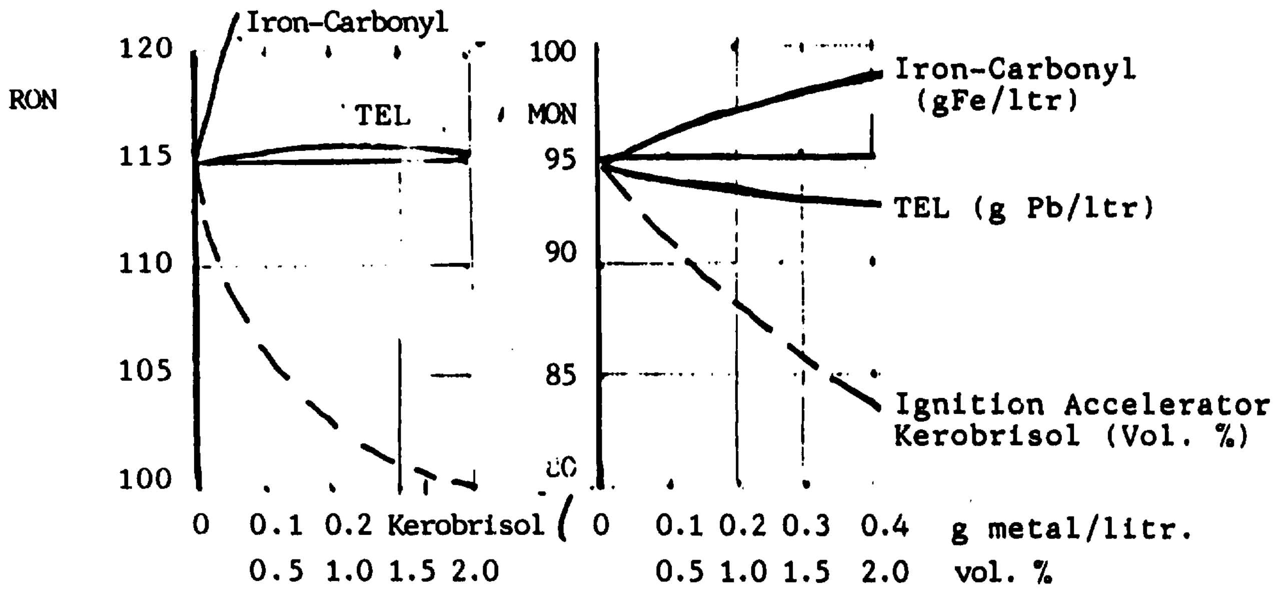
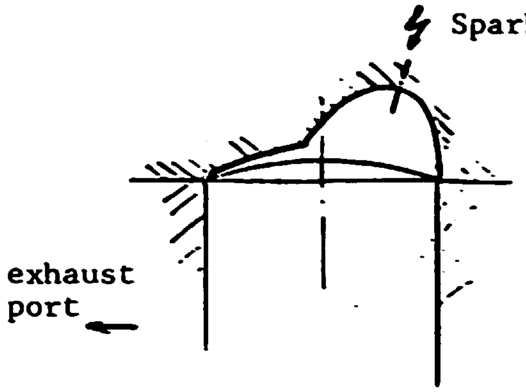
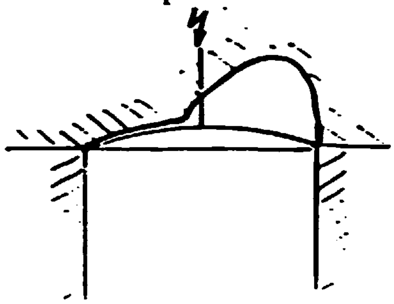


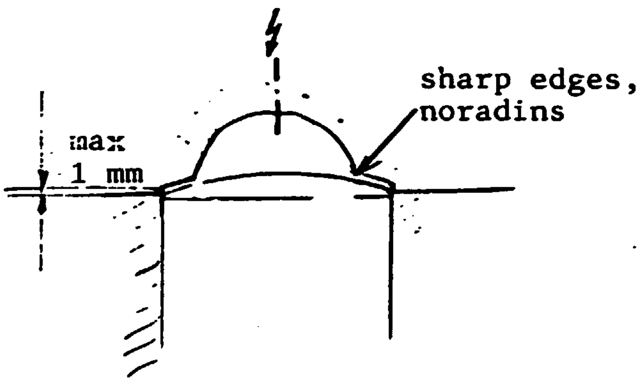
Fig. 22 Influence of anti-knocking additives and ignition accelerators on the octane numbers of the methanol [11]



a) mass production combustion chamber position



b) changed spark plug position



c) rotational symmetrical ball shaped combustion chamber with surrounding squish area

Fig. 23 Proposed steps for abnormal combustion reactions

English
2 March 1987

Application of Alternative Fuels for Internal Combustion Engines

DP/IND/82/001/12.01

INDIAN INSTITUTE OF PETROLEUM
DEHRADUN, INDIA

PRELIMINARY WORK PROGRAMME

by

Prof. VOLKMAR KUENTSCHER
Expert on Design and Development of
Internal Combustion Engines

UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION

1. INTRODUCTION

Refering to the revised JOB DESCRIPTION of September 17, 1986 the title of the post was Expert on "Design and Development of Internal Combustion Engines" (DP/IND/82/001/11-01/133 12). The purpose of the project is to develop and establish suitable technologies for utilization of alcohol (methanol) as an alternative fuel for use as an alternative fuel for use as partial of total replacement of motor gasoline in two-stroke spark ignition engines and diesel oil in compression ignition engines.

The expert will be expected to assist the Indian Institute of Petroleum specifically in the following areas:

1.1 Advise on the design aspects of fuel introduction, combustion exhaust emission, lubrication and wear.

1.2 Assist in development of prototype systems and devices.

1.3 Advise in planning of experiments on research engines and on test benches to meet the project objectives.

The expert will also be expected to train Indian Institute of Petroleum (IIP) technical personnel in the above mentioned items.

By a letter from the UNDP Methanol Project Coordinator, Mr. Sudhir Singhal at Indian Institute of Petroleum of December 23, 1986 the post was explained more precisely as partici-pation particularly in -

- Development of an electronically 2-stroke engine for methanol utilization

- Improvements in scavenging processes of 2-stroke engines.

The duration of the present mission of the expert is from 23 February 1987 to 22 April 1987 including travelling and briefing/debriefing by UNIDO in Vienna and Delhi, resp. so the writer carried on February 27, 1987 in Dehra Dun and got the first impressions of the facilities and the main tasks of Petroleum Products Application Division at IIP.

In accordance with Dr. Seidel's recommendations (UNIDO Vienna) firstly to become familiar with the recent final reports of UNDP experts on this field, I propose after one day studies the following preliminary work programme. This programme can be revised more precisely by the author during his present mission.

2. WORK PROGRAMME

According to the above mentioned UNDP Project Coordinator's letter at IIP the task comprises two main subjects -

- The improvement offuel economy of both gasoline and methanol two-stroke engines by an improved scavenging process in general refering to the recent achievements in two stroke engine design and investigation techniques of the scavenging process,

- The application of new fuel introduction techniques by application of electronically controlled fuel dosage systems.

2.1 IMPROVEMENTS OF SCAVENGING PROCESS OF 2-STROKE ENGINES

For solving the problem it is necessary to design and to construct a test bench (Jaros test bench) for scavenging investigations and the necessary measurement techniques corresponding to pp 5-8 and Figures 10-12 of reference [1]. Therefore the author proposes to the UNDP ProjectCoordinator at IIP -

- To assign immediately a responsible engineer for the scavenging investigations and to give him the following tasks :

2.1.1. Delivering the required electrically driven air blower with a flow rate of at least $5m^3$/min and at a pressure rate of 400 mm water column.

2.1.2. Fabrication of a set of four U-shaped water manometers (length 1 m approx).

2.1.3. Design and fabrication of the air receiver with blow-by valve, the basic plate for cylinder mounting completed with a device for the correct piston positioning. This work is to be done in close consultation with the writer.

2.1.4. Delivering of an exit air stream volume rate meter. This should be preferably a standardized Venturi jet with an inner Venturi diameter of 32 mm and an inner diameter of the connecting tubes of 51 mm.

2.1.5. Attaching the required pipes and tubes.

2.1.6. Choosing the engines to be investigatedtomeet the requirements of the UNDP Programme. This should be done in discussions with the writer, the Project Coordinator and the responsible engineers. For this reason the drawings of the engines to be investigated are needed immediately. Details of the scavenging system and transfer ports, resp., should be visible in details.

2.1.7. Design and fabrication of a test cylinder head containing the two pilot tubes (shape A and B see Fig. 10, Ref.(11) in consultation with the writer. The pitot tubes must be made to swivel radially and moveable in cylinder axis direction.

2.1.8. Design and fabrication of (a) test cylinder(s) allowing the replacement of transfer ports by special casings containing different modified transfer ports for the optimization of the scavenging process (Fig.1).

2.1.9. During the fabrication of the test bench, the test cylinders and cylinder heads special papers with a grid corresponding to the pitot tubes position (See Fig.11, Ref.1) should be prepared.

2.1.10. Drawing a grid of the Charge Trapping Probability for 50% engine Stroke (See Fig.12, Ref.1).

2.2. Application of New Fuel Introduction Techniques by Application of Electrocially controlled fuel dosage systems

There are different fundamental approaches to apply electronically controlled fuel dosage.

2.2.1. Electronically controlled carburettor applying ether

- a very lean basic mixture delivered by the main carburettor jet enriched by an electronically triggered additional fuel jet controlled by a solenoid and an Electronic Control Unit (ECU)

- a rich basic mixture delivered by the main fuel jet-leaned by an electronically trigged airjet with a solenoid and an ECU.

2.2.2. Electronically contrclled fuel injector system as low pressure injection

Electronically controlled gasoline injection systems as low pressure system are available in the international market. They are especially designed for manifold injection (see Ref.2). Such a system was already tested in India at the Karnataka Regional Engneering College, Surathkal (as a 4-stroke methanol fueled stratified charge engine [2].

Since the electronically controlled gasoline injection systems - produced by specialized international companies only allow low injection pressures (upto 0.3 MPa) - for the special task at IIP e.g. methanol injection in 2-stroke engines, only injection in the inlet pipe or in a transfer port is applicable.

In this way fuel consumption and HC emissions can be probably reduced but fuel scavenging losses are still existing.

2.2.3 Direct fuel injection into the cylinder by an electronically controlled fuel injection

From the stand point of fuel consumption and HC emissions reductions a system should be applied which injects the fuel very late, e.g. after exhaust port closes. But the writer drew up the conclusion from his own experiences and his own investigations (See Ref.[3], [4] and [5] Fig.1) that only fuel injection from the cylinder head against the scavenging stream of the two-stroke could /not settle this problem. The required mixture formation period (between fuel injection ends and the optimum ignition advance angle) was too long so that one must inject the fuel at bottom dead centre (B.T.C.) approximately. Though fuel consumption and HC emission reductions could be achieved but not to the desired low level. So the author's team prepared a modified stratified combustion chamber with an intensive air swirl created by the scavenging stream and supported by a Squish stream between cylinder head and piston crown. This reduced the required mixture formation period ([14] Fig. 6 and 7), gave improved fuel economy and allowed the engine to run un-throttled even when idling. Though the HC emissions in volumetric terms (ppm) remained very low the absolute mass flow of HC was not yet sufficently reduced since the engine runned unthrottled. This resulted in an about four times increased gas flow rate through the engine in the whole load and speed range.

Therefore there was a demand in a redesign of the engine applying a lean burn combustion system giving the required fuel consumption reduction of 5 - 35 % depending from load and engine speed (See Ref [4] Figures 11 and 12).

Through this system it successfully tested in prototype engine also by US research [5] engineers it seems to be sensitive for methanol application. Since methanol evaporates at comparetively low temperatures the danger of vapour lock formation in the injection nozzle positioned in the heated cylinder head may occur. Additionally the heat of the cylinder head contributes to coke deposit formation from lubricating oil. This can destroy the desired fuel spray pattern. That's why the writer proposes a fuel injection system with a spray direction upwards [6] to the cylinder head into the combustion (see Fig.2).

..3. Proposals for the Beginning of Investigations on Electronic Fuel Injection (E.F.I.) for Methanol Fuelled Two-stroke Engines

The writer proposes the following items for creating an E.F.I. system:

2.3.1 It is necessary to assign immediately two engineers for preparation, calculation, design and finally fabrication of the desired injection system. Theengineers should be

- one engineer on the field of mechanical engineering (Int. Combustion engg.)

- one engineer on the field of electrical and electronical engineering.

2.3.2. The writer should get the opportunity in the 1st week of March to present a paper with slides dealing with electronically controlled fuel injection systems in two-stroke engines for interested people of IIP, the responsible engineers and the Project Coordinator. This is necessary for advising the responsible personnel and the Project Coordinator.

2.3.3. Make a decision in a special meeting with the responsibile engineers, scientists, the Project Coordinator and the writer which system should be applied corresponding to items 2.2.1 - 2.2.3 and then designed and fabricated.

It is necessary to take into consideration.

- which components are available for IIP, including a separate lubrication pump,

- which components can be fabricated as prototypes in IIP or in cooperation

- choice of the engine type

2.3.4. Beginning the system calculation and design corresponding to the decision of item 2.3.3. by the responsible engineers in close consultations with the author. It is necessary to add that the complete calculation and design corresponding to Annexure II needs a special training.

References

[1] Sharma, J. Technical Report of Training at Engineering University Zwickau, German Democratic Republic in the Area of Two-Stroke Engine Scavenging under UNDP Fellowship.
Report No.EL 8087, Indian Institute of Petroleum, Jan. 1987.

[2] Samaga, B.S., Suresh Babu P.V., Suresh Kumar, Y; Performance Studies of Methanol Fuelled Stratified Charge Combustion Engines
Proceedings VII International Symposium on Alcohol Fuels Paris 20/23 October 1986 pp 142-147.

[3] Kuentscher V., Olbrich, C. Baumqaertel C.; A Two-Stroke Engine with Charge Stratification and Electronically Controlled Pressure Impact Injection
Paper C401180, 2nd Stratified Charge Conference London 1980 organized by the Institution of Mechanical Engineers.

[4] Kuentscher,V.; Application of Charge Stratification, Lear Burn Combustion Systems and Anti-Knock Controll Devices i Small Two-Stroke Cycle Gasoline Engines
SAE Paper 860127 presented at the International Annual Conference of the Society of Automotive Engineers Detroit, February 1986.

[5] Beck, N.J.Jolmson, W.P.; Barkhimer R.L., Patterson, S.H.; Electronic Fuel Injection for Two Stroke Cycle Gasoline Engines; SAE Paper 860906

[6] Mixture Formation Technique for Two-Stroke Otto Engines
Technical Know How of Engineering University, Zwickau, GDR.

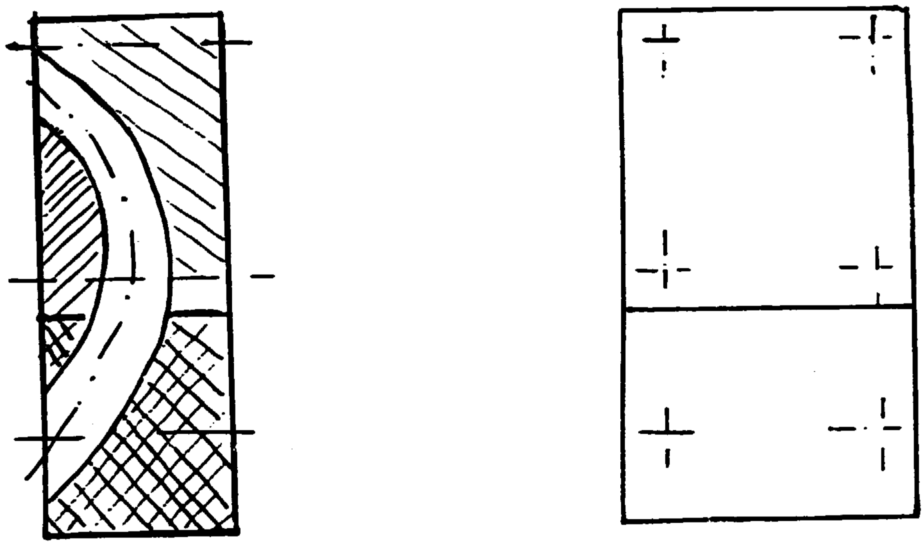


Fig. 1 Casings with different shapes of transfer port

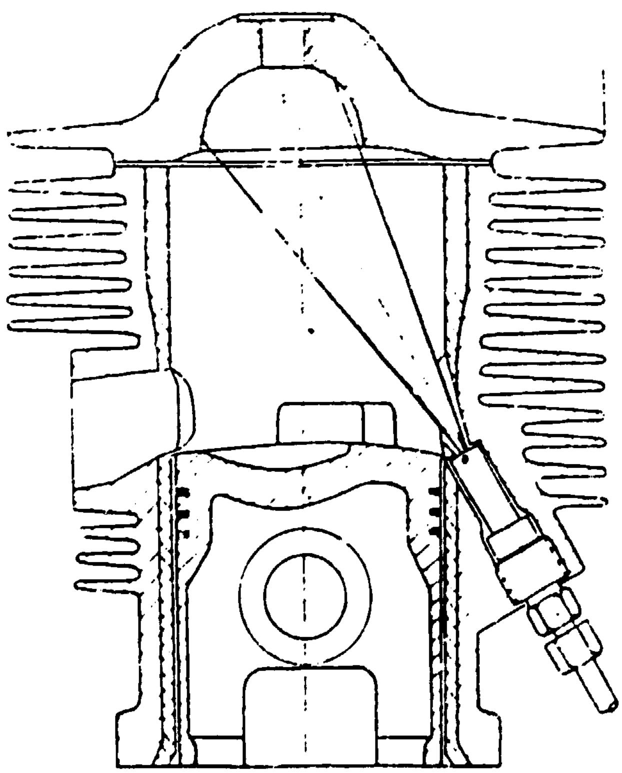


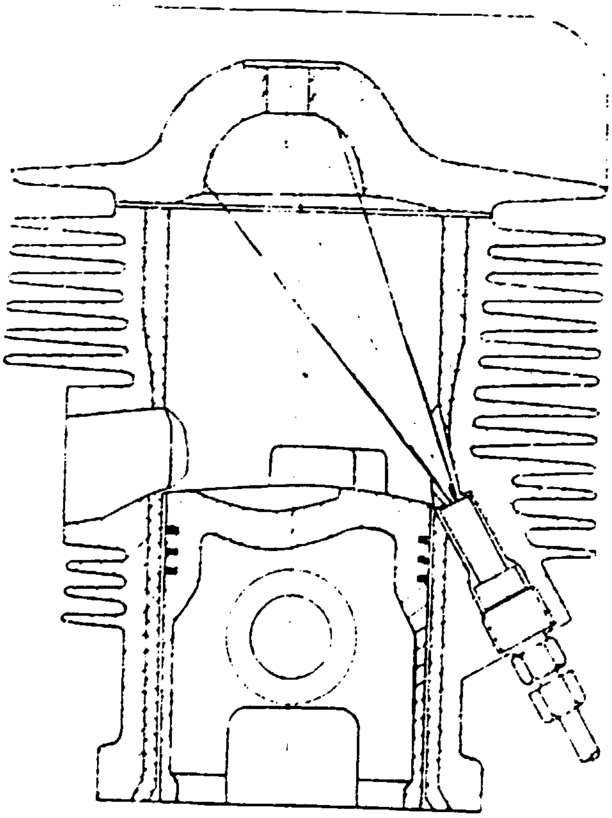
Fig. 2 Fuel injection in direction of the cylinder head

UNIVERSITY OF ENGINEERING
ZWICKAU
GERMAN DEMOCRATIC REPUBLIC

Mixture formation technique for two-stroke Otto engines

Our concept for fuel-saving and non-polluting reciprocating piston type engines combines two-stroke operation with an electronically controlled petrol injection system for internal mixture formation. For many years, we have been doing intensive research work in this field.

As a result, we offer the technical solution for a mixture formation technique utilizing the hydraulic-ram principle and electronically controlled direct fuel injection into the cylinder, this systems being an achievement of our institution as well.



Thus, we guarantee:

- reliability and long life of the injection nozzles due to their special arrangement
- exact fuel dosing for all loads, connected with an obvious charge stratification effect
- engine speeds up to 6500 rev./min

Advantages

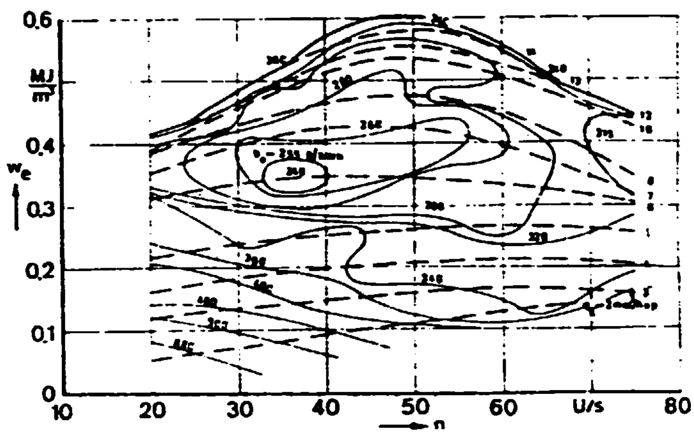
- The fuel consumption of this system may be compared to that of advanced four-stroke Otto engines. Especially for partial load, it may be even lower.
- NO_x emission as compared with corresponding four-stroke Otto engines is only 30 ... 50 %.
- CO and CH emissions equal those of corresponding four-stroke Otto engines.

We offer:

the technical know how

- on the specific mixture formation and combustion technique
- on the type of the injection nozzle to be used and on injection nozzle arrangement

If required, we will make a special offer for the electronically controlled ram-tuned injection system.



Characteristics of a two-cyl. two-stroke gasoline engine with in-cylinder fuel injection by the ram tuned electronically controlled system

Consult the University of Engineering Zwickau!
Our scientists will readily answer your questions.

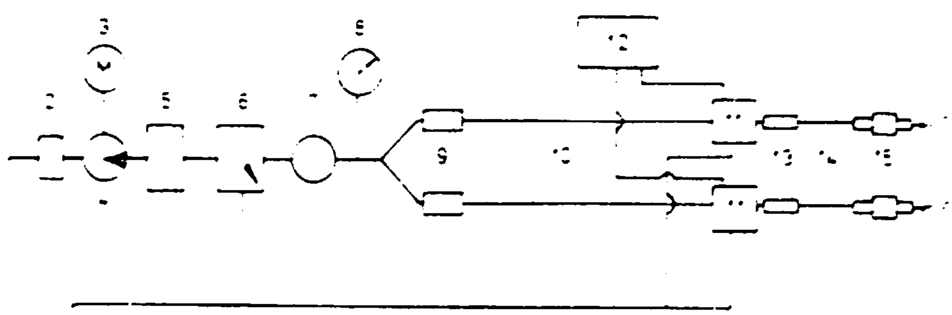
Ingenieurhochschule Zwickau
Direktorat Forschung
Dr.-Friedrichs-Ring 2a
Zwickau
DDR-9540

Telefon: 82 23 38 Telex: 77 038

UNIVERSITY OF ENGINEERING
ZWICKAU
GERMAN DEMOCRATIC REPUBLIC

Hydraulic-ram-tuned electronically controlled fuel injection system

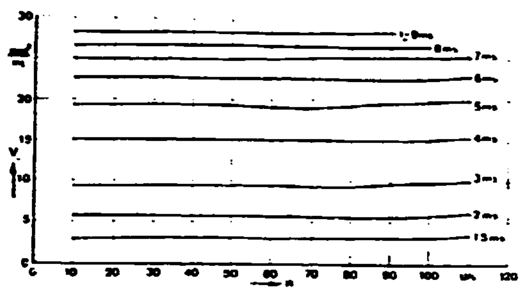
As a result of long research work we developed an injection system on the basis of the hydraulic ram principle. An essential advantage of this electronically controlled injection system is that it opens new possibilities for fuel dosing by adapting both the amount of fuel injected and the duration of the injection process to the specific requirements of the combustion engine.
It is this property, connected with electronic characteristics' storage, which makes this injection system especially suitable for its application in two-stroke Otto engines.



1 tank	6 pressure control valve	11 blocking valve
2 coarse filter	7 receiver	12 electronic unit
3 pump motor	8 pressure indicator	13 non return valve
4 pump	9 wave compensator	14 injection tube
5 fine filter	10 ram tube	15 injection nozzle

Ram tuned electronically controlled injection system for a two-cylinder two-stroke engine

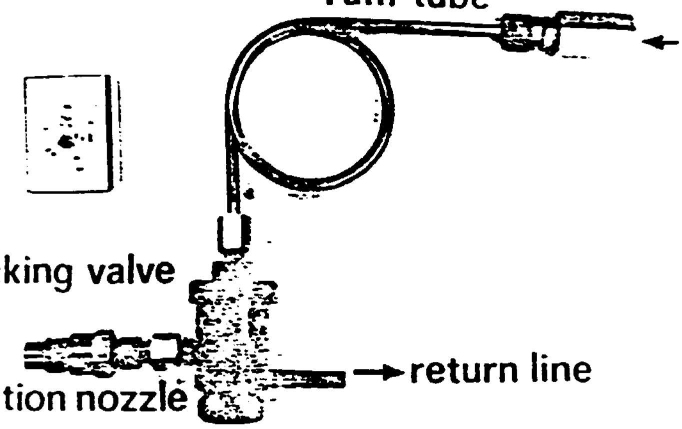
The functioning principle is equally simple and advantageous for controllable fuel injection.
An electromagnetically controlled valve realizes controllable transformation of kinetic flow energy into pressure energy.



Amount of fuel injected in dependence on the injection frequency for various opening times of the valve

The technological requirements of the ram-tuned injection system are relatively low. Its advantages as compared with conventional direct injection systems are enormous:

- engine speed independent pressure characteristic as a precondition for good mixture formation with all engine load ranges
- electronic control results in optimum adaptability of the amount of fuel to be injected and of injection timing
- operational frequencies of more than 100 Hz
- production accuracy requirements are lower than with mechanical injection systems
- lubrication-free



Application

- high-speed two-stroke Otto engines with internal mixture formation

Effects

- optimum fuel consumption and exhaust gas emission connected with decreased construction efforts as compared with certain four-stroke Otto engines

Offer

- scientific foundations of injection system dimensioning and design

Consult the University of Engineering Zwickau!
Our scientists will readily answer your questions!

Inquiries, please, to:

Ingenieurhochschule Zwickau
Direktorat für Forschung
Dr.-Friedrichs-Ring 2a
Zwickau
DDR-9540
Phone: 82 32 38 Telex: 77038

ANNEX B

PROPOSAL FOR A LECTURE PROGRAMME FOR IIP/
PETROLEUM PRODUCTS APPLICATION DIVISION
7 LECTURES (ONE LECT. A WEEK)

1.	Application of Charge Stratification, Fuel Injection, Lean Burn Combustion systems and Anti-Knock Devices in Small Two Stroke Otto Cycle Engines	March 4, 1987-11.30
2.	First Experiences with Mixture Injection Application - A Possibility of Avoiding Charge Exchange Losses in Two-Stroke Engines	March 11, 1987-11.30
3.	An Anti-Knock Combustion and Ignition System for Two-Stroke Otto Engines	March 18, 1987-11.30
4.	Findings on possible improvements of Two-Stroke Otto Engines Triboproperties	March 25, 1987-11.30
5.	Single Cylinder Two-Stroke Otto-Engine Anti-Noise Investigation	April 1, 1987-11.30
6.	Equipping a Former Truck Diesel Engine on Town Gas Fueling	April 8, 1987-11.30
7.	M100 Application in a Redesigned Former Truck Diesel Engine.	April 15, 1987-11.30

4.3.87

Persons encountered in connection with the mission

Mr. P.N.Pathak	Programme Officer, UNDP, New Delhi
Dr. R.Krishna	Director, IIP.
Mr. S.Singhal	Head, Petroleum Products Application Division, IIP and Project Coordinator, UNDP Project.
Dr. B.P.Pundir	Project Coordinator, Eng. Lab/IIP.
Mr. M.Saxena	Eng. Lab/IIP
Mr. M.Gupta	Eng. Lab/IIP
Mr. P.G.Khanwalkar	Electronic Engineer, Eng. Lab/IIP.
Mr. M.Abraham	Eng. Lab/IIP
Mr. J.Sharma	Eng. Lab/IIP
Mr. S.Maji Eng. Lab/IIP	Eng. Lab/IIP
Mr. S.K.Jain	Eng. Lab/IIP
Mr. B.K.Puri	Eng. Lab/IIP.
Mr. Sumer Chand	Eng. Lab/IIP.
Mr. Rajender Singh	Eng. Lab/IIP.
Mr. G.S.Bhargava	Head, Industrial Liaison/IIP.
Mr. K.K.Kaul	Industrial Liaison Services/IIP.
Mr. J.C.Khosla	Consultant (Marketing), Oil & Natural Gas Commission, Dehra Dun

Computer programme for the calculation of the probable trapping efficiency ω of the area elements

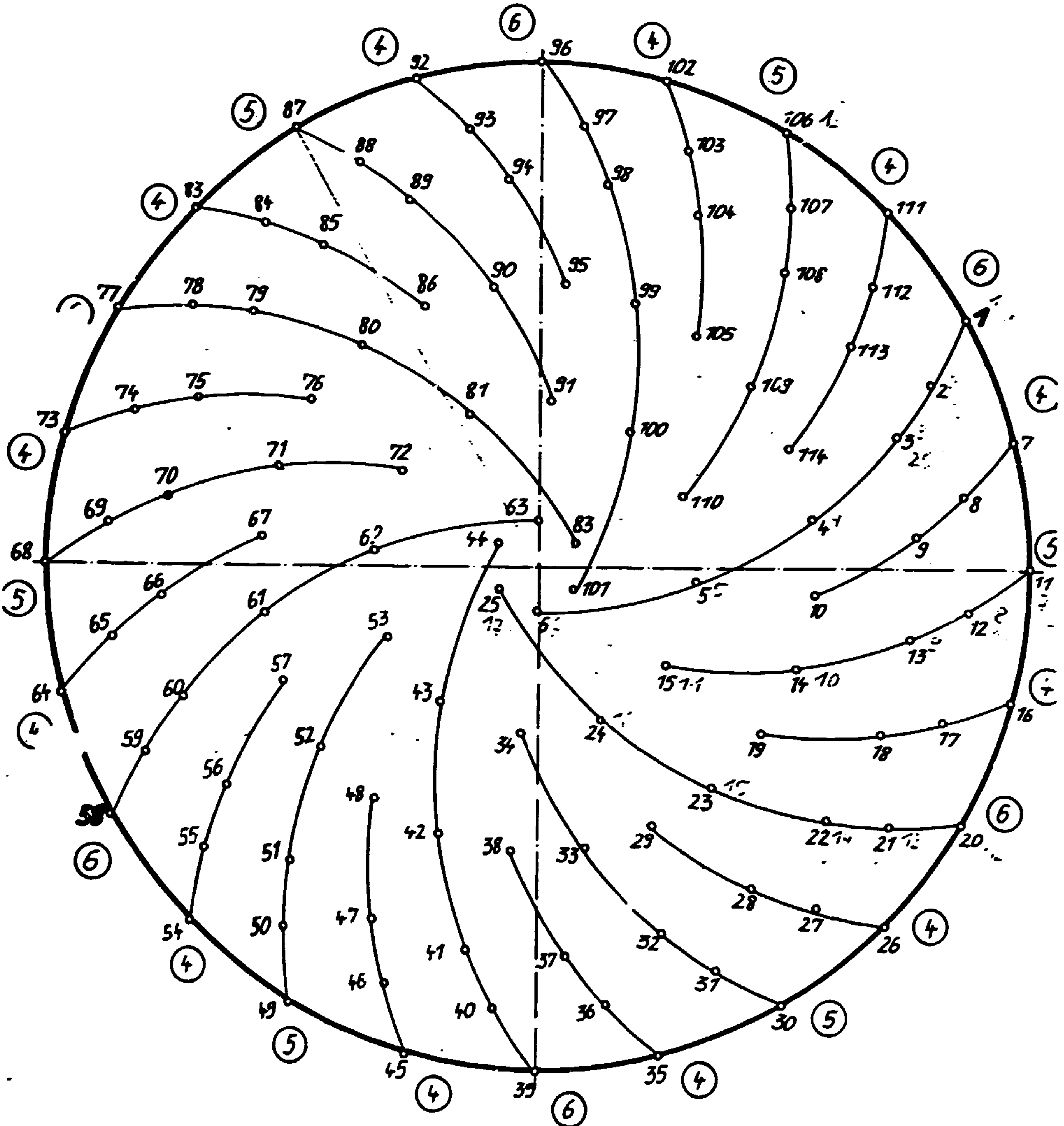
```
1Ø    REM Calculation of OMEGA
2Ø    PRINT "Input of the constant value"
3Ø    INPUT "Z(mm)    =";Z
4Ø    INPUT "ZM(mm)   =";ZM
5Ø    INPUT "D(mm)    =";D
6Ø    PRINT: PRINT" "Input of the variable values"
7Ø    INPUT "R(mm)    =";R
8Ø    INPUT "AG(Grad)=";AG
9Ø    INPUT "EG(Grad)=";EG
1ØØ   INPUT "SG(Grad)=";SG
11Ø   INPUT "P        =";P
12Ø   CLS
13Ø   AB=AGxPI / 18Ø
14Ø   EB=EGxPI / 18Ø
15Ø   SB=SGxPI / 18Ø
16Ø   FOR PH=AB TO EB STFP SB
17Ø   PG=PH=18Ø / PI
18Ø   X= - (RxSIN(PH))
19Ø   Y= (D/2) - (RxCLS(PH))
2ØØ   H= (Z-ZM)/Z
21Ø   OM= (Xx2xYx2 - (2xYxDxHx(1-H)))/(YxDx(1-2xHx(1-H)))
22Ø   IF OM<Ø THEN GOTO 23Ø : ELSE GOTO 24Ø
23Ø   OM=Ø
24Ø   PRINT "P        =";P
25Ø   PRINT
26Ø   PRINT "OM       =";OM
27Ø   PRINT
28Ø   PRINT
29Ø   PAUSE 5Ø
3ØØ   P=P+1
31Ø   NEXT PH
32Ø   END
```

Calculation of the air velocity and the trapping efficiency corresponding to the measured pressure values from the scavenging test bench

```
10     WINDOW: CLS
20     PRINT" "Calculation of trapping efficiency and air velocity"
30     WINDOW 4,23,0,39
40     DIM A(70) : DIM B (70) : DIM OM (80) : DIM P (70): DIM PD (70)
50     DIM W(70) : DIM L (80) : DIM X (80) : DIM Y (80): DIM Z (80)
60     PRINT" "Input of the starting values"
70     PRINT
80     FOR I=1 TO 66
90     PRINT "A("I") = "
100    PRINT "B("I") = "
110    PRINTTAB (8) : INPUT A(I)
120    PRINTTAB (8) : INPUT B(I)
130    PRINT
140    NEXT I
150    CLS
160    PRINT "Input of the air values"
170    PRINT
180    INPUT "T (K)  = ";T
190    INPUT "PB (mm CLS) = ";PB
200    CLS: PRINT : PRINT : PRINT : PRINT
210    PRINT : PRINT : PRINT : PRINT
220    PRINTTAB (10) "WAITE"
230    PRINT
240    PRINTTAB(4) "I am being about to calculate"
250    OM(1) = 0,...
1030   OM(79) =
1040   D(1)   =
1050   D(2)   =
1060   D(3)   =
1070   D(4)   =
1080   D(5)   =
1090   D(6)   =
1100   D(7)   =
1110   D(8)   =
1120   D(9)   =
1130   RO = (PB x 13.6 x 9.81)/(Tx287)
```

```
1140  FOR I = 1 TO 66
1150  P(I) = (A(I) - B(I))/2
1160  NEXT I
1170  FOR L = 1 TO 79
1180  I = L
1190  IF (L=12 OR L=24 OR L=36) THEN GOTO 1200
      ELSE GOTO 1210
1200  X= I+1 : Y= I+12 : Z= I-11 : GOTO 1490
1210  IF (L>=1 AND L<=35) THEN GOTO 1220:ELSE GOTO 1230
1220  X = I+1 : Y = I+12 : Z = I+13 . GOTO 1490
1230  (F(L >= 37 AND L<= 47) THEN GOTO 1240 : ELSE GOTO 1250
1240  X=I : Y=I+1 : Z= I+12 : GOTO 1500
1250  IF (L=48) THEN GOTO 1260 : ELSE GOTO 1270
1260  X=I : Y= I-11 : Z= I+12 : GOTO 1500
1270  IF (L >=49 AND L<=59) THEN GOTO 1280 : ELSE GOTO 1290
1280  X=I : Y = I+1 : Z = I-11 : GOTO 1500
1290  IF (L=60) THEN GOTO 1300 : ELSE GOTO 1310
1300  X=I : Y=I-11 : Z=I-23 : GOTO 1500
1310  IF (L=61) THEN GOTO 1320 : ELSE GOTO 1330
1320  X=I : Y=I-12 : Z=I-11 : GOTO 1500
1330  IF (L >=62 AND L <=66) THEN GOTO 1340 : ELSE GOTO 1350
1340  X=I : Y=Y+2 : Z = Z+2 : GOTO 1500
1350  IF (L=67) THEN GOTO 1360 : ELSE GOTO 1370
1360  X=I-6 : Y=I-17 : Z=I-16 : GOTO 1500
1370  IF (L >=68 AND L<=71) THEN GOTO 1380 : ELSE GOTO 1390
1380  X=I-6 : Y=Y+2 : Z=Z+2 : GOTO 1500
1390  IF (L=72) THEN GOTO 1400 : ELSE GOTO 1410
1400  Z=I-6 : Y=Y+2 : X=I-23 : GOTO 1500
1410  IF (L=73) THEN GOTO 1420 : ELSE GOTO 1430
1420  X=I-12 : Y=I-11 : Z=I-22 : GOTO 1500
1430  IF (L >=74 AND L <= 77) THEN GOTO 1440 : ELSE GOTO 1450
1440  X = X+1 : Y=Y+1 : Z=Z+2 : GOTO 1500
1450  IF (L=78) THEN GOTO 1460 : ELSE GOTO 1470
1460  X=X+1 : Y=X-5 : Z=X-17 : GOTO 1500
1470  IF (L=79) THEN GOTO 1480
1480  X=61 : Y=62 : Z=63 : S=64 : T=65 : U=66 : GOTO 1510
1490  PO(L) =(P(I)+P(X) + P(Y) + P(Z))/4 : GOTO 1520
1500  PP(L) = (P(X)+P(Y)+ P(Z))/3 : GOTO 1520
```

```
1510   PD(L) = (P(X) + P(Y) + P(Z) + P(S) + P(T) + P(U))/6
1520   IF P(I)> = 0 THEN GOTO 1530 : ELSE GOTO 1540
1530   W(I) = SQR (2xP(I)/RO) : GOTO 1574
1540   P(I) = -P(I)
1550   W(I) = SQR (2xP(I)/RO)
1560   W(I) = -W(I)
1570   IF (PD(L)<0) THEN PD(L) = 0
1580   IF (L>=1 AND L<=12) THEN Q=1
1590   IF (L>=13 AND L<=24) THEN Q=2
1600   IF (L>=25 AND L<=36) THEN Q=3
1610   IF (L>=37 AND L<=48) THEN Q=4
1620   IF (L>=49 AND L<=60) THEN Q=5
1630   IF (L>=61 AND L<=66) THEN Q=6
1640   IF (L>=67 AND L<=72) THEN Q=7
1650   IF (L>=73 AND L<=78) THEN Q=8
1660   IF (L = 79)THEN Q=9
1670   ZZ=SQR ( PD(L)) x CM (L) x D(Q)
1680   NN=SQR (PD(L)) x D(Q)
1690   ZS=ZS+ZZ
1700   NS=NS+NN
1710   CLS
1720   IF (I>=67) THEN GOTO 1750
1730   PRINT " W("I") = "; W(I)
1740   IF (I=17 OR I=34 OR I=51 OR I=66) THEN PAUSE : CLS
1750   NEXT L
1760   PAUSE
1770   ET=ZS/NS
1780   CLS
1790   PRINT
1800   PRINT "Output trapping efficiency"
1810   PRINT : PRINT : PRINT : PRINT
1820   PRINT "ETATR=";ET
1830   PAUSE : WINDOW : CLS
1840   END
```



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