SAE The Engineering Resource For Advancing Mobility

New Developments in Electronic Engine Management

SP-572

International Congress & Exposition
Detroit, Michigan
February 27-March 2, 1984

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Published by:
Society of Automotive Engineers, Inc.
400 Commonwealth Drive
Warrendale, PA 15096
February 1984

ISBN 0-89883-343-4
SAE/SP-84/572
Library of Congress Catalog Card Number: 83-51757

Printed and Bound by Publishers Choice Book Mfg. Co.
Mars, Pennsylvania 16046

PREFACE

Electronic controls as applied to the passenger car powertrain is a rapidly progressing sequence of events. What started as only a solid state ignition control module in the early 1970's has grown into a full scale multivariable input/output electronic powertrain control system for vehicles with internal combustion engines. What was, just 10 years ago, considered as strictly aerospace technology, both in sophistication and reliability, now exists under the hood of our automobiles.

Consequently, two full-day sessions at the 1984 SAE Congress and Exposition are devoted to the state-of-the-art in Electronic Engine Management and Driveline Controls. These sessions deal with newly-announced electronic products in ignition, transmission, fuel, and air controls while explaining the extraordinary new benefits that lie ahead for the consumer. Moreover, certain papers offer innovative new directions for internal combustion engine control laws, which possibly could simplify and optimize the control processes.

Microprocessor and memory-based electronics largely make up the modern controllers in today's automobiles. Even five years ago, and when memory size was small, the adaptation of microprocessors to engine control was difficult, and engine/vehicle calibration was performed with a lot of trial and error on the part of the application engineer.

However, in the modern automobile, where 16K, 32K, and 64K ROM's are being planned for multivariable control systems, the old trial and error methods are impossible. Necessarily, great progress has been achieved in automating calibration techniques and in software programming productivity. This leads to a significant manpower savings, when one considers the effort required while calibrating the hot, cold, and warm-up profiles over the entire engine/vehicle operating ranges, when the vehicle is to be optimized for fuel, air, spark, and transmission operation. Several included papers treat these developments and offer the readers some potentially valuable tips.

Some of today's automobiles use 10 or more microprocessors, and by 1990 passenger cars will average over $900 in electronic packages. This compendium of papers will give the reader some good insight on how the industry is planning to get there.

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Microcomputer Mechanical Clutch and Transmission Control

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ABSTRACT

AN ELECTRONIC CONTROLLED FULL AUTOMATIC TRANSMISSION has been developed. Automatically controlled dry clutch and synchromeshed gear transmission make driving easier, maintaining better fuel efficiency of a mechanical transmission. The electronic control, similar to use of manual transmission, and H-pattern floor shift type "selector lever," only for electric input device, make it possible for the driver to choose either of two types of driving - "sporty driving" of a manual transmission and "easy driving" of an automatic transmission. In the automatic mode, the microprocessor makes it possible to have stop-and-go operation that is so troublesome with a dry clutch. Adoption of a new brake system improves safety on ascending grade starts without torque converters.

This paper describes the system, in some detail on following subjects;

Clutch and Transmission Actuators
Sensors and Electronic Control Unit
System Control Strategy
Running Data

INTRODUCTION

INCREASING ACCEPTANCE OF AUTOMATIC TRANSMISSIONS (A/T) WORLDWIDE reflects the great customer need for ease of operation and safety. On the other hand, since the 1973 oil crunch there has been an increasing demand for better fuel economy.

To meet these new market trends, automotive manufacturers have been trying to develop new transmissions including a continuously variable transmission (CVT), which is not yet available for practical use. The solutions the automotive industry offered so far are improvements in the conventional torque converter A/T - the addition of overdrive gear, lock-up clutch and employment of electronic controls, an approach to "economy drive" from "easy drive".

Another is an approach to "easy drive" from "economy drive" - application of electronic controls to an economically-proven dry clutch and multi-speed manual transmission (M/T). An electroniccally controlled transmission (ECT) that we have developed is operated by actuators controlled by an electronic control unit (ECU) without changing basic design of the 5-speed manual transmission with dry clutch. The ECT has been developed with emphasis on offering, in addition to good fuel economy and ease of drive, "pleasure of driving" to the drivers who prefer manuals because of sporty feel of manual shift, a factor which has not been given much attention - in fact there are not a few drivers in Japan and Europe who enjoy sporty driving by manually and quickly selecting the gears as they please.

NEEDS / OFFERS	EASY DRIVE	FUEL ECONOMY	ENJOYABILITY
HYDRAULIC TRANSMISSION	○	ADDITION OF OD GEAR LOCK UP CLUTCH △ ⇨ ○	△
MECHANICAL TRANSMISSION	△ ⇨ ○	○	○
CONTINUOUSLY VARIABLE TRANSMISSION (CVT)	○	UNDER DEVELOPMENT (?)	(?)

TARGET OF ELECTRONICS TECHNOLOGY

Fig.1 - Needs of transmission

POWER TRAIN AND CONTROL SYSTEM

THE ECT is applied to Isuzu ASKA, J-car FWD (Front wheel drive), powered by transversely installed 2,000 cc gasoline and diesel engines. The power train control system, as shown on the system block diagram (Fig.2), consists of an ECU, selector lever and accelerator pedal operated by the driver, a number of sensors which detect operating conditions, actuators for the carburetor (or the injection pump), clutch and transmission, and the power source for the actuators.

THE ENGINE is a 2,000 cc SOHC gasoline (or diesel), which has been in production, and only one modification, addition of a stepper motor as a throttle actuator, is applied. The stepper motor is connected by linkage with the carburetor (or the injection pump). The ECU actuates the stepper motor in accordance with the detected accelerator pedal stroke, thereby opening and closing the throttle valve as required.

THE CLUTCH is of a diaphragm-spring type dry single-disc friction clutch, which has been in production. The travel of the release bearing is controlled by the clutch actuator, not by depressing the clutch pedal.

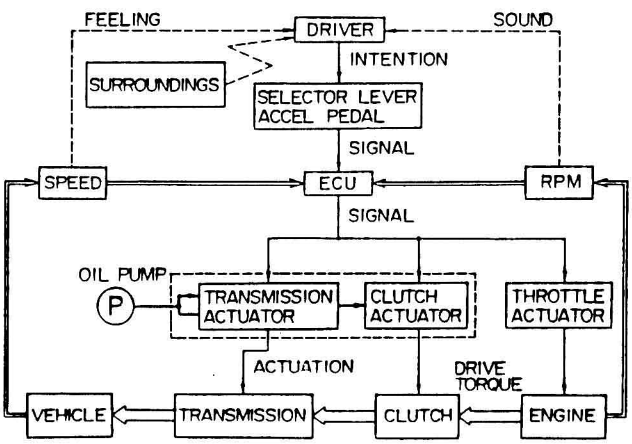

Fig.2 - System block diagram

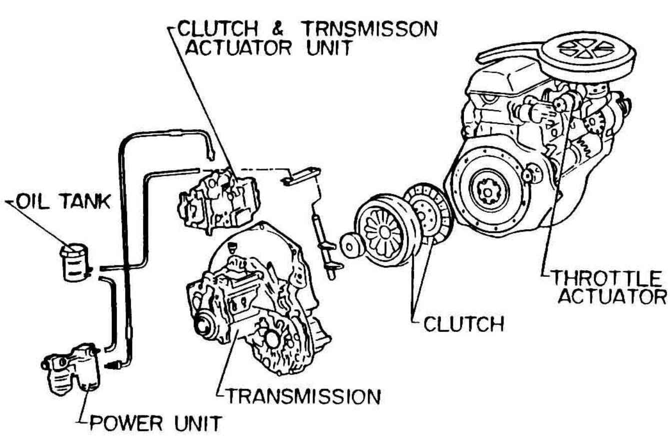

Fig.3 - Power train

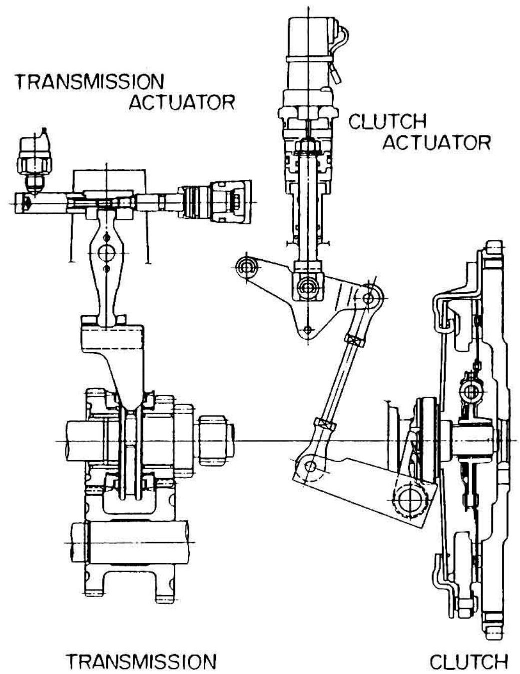

Fig.4 - Clutch and transmission actuators

THE TRANSMISSION is a 5 forward speed synchromesh type (backward slidingmesh), which is carriyed over from a manual transmission model without any design change. Gear shift and selection are operated by means of the transmission actuator in place of a change lever and remote control cables.

THE HYDRAULIC POWER SOURCE of the actuators is a motor-driven gear pump with an accumulator.

CLUTCH AND TRANSMISSION ACTUATORS

THE CLUTCH and transmission actuators are assembled into one unit, comprizing a clutch operating servo cylinder with a clutch stroke sensor and 3-position stop type shift and select cylinders.

The clutch actuator is controlled by a solenoid intake valve (V2) and two solenoid relief valves (V3 and V4). When the intake valve (V2) is opened with the relief valves (V3 and V4) closed, high-pressure fluid is forced, against the force of the clutch diaphragm spring, into the servo cylinder to disengage the clutch. When the intake valve (V2) is closed with the relief valves (V3 and V4) closed, the clutch is held disengaged.
When the relief valves (V3 and V4) are opened with the intake valve (V2) closed, the fluid pressure in the cylinder is dissipated into the atmospheric pressure, and the fluid is forced into the reservoir by the force of the diaphragm spring, thereby engaging the clutch. Regarding the two relief valves, one solenoid valve (V4) has a larger-diameter passage, while the other (V3) has a smaller-diameter passage. Clutch engaging speed is controlled by chopping control,

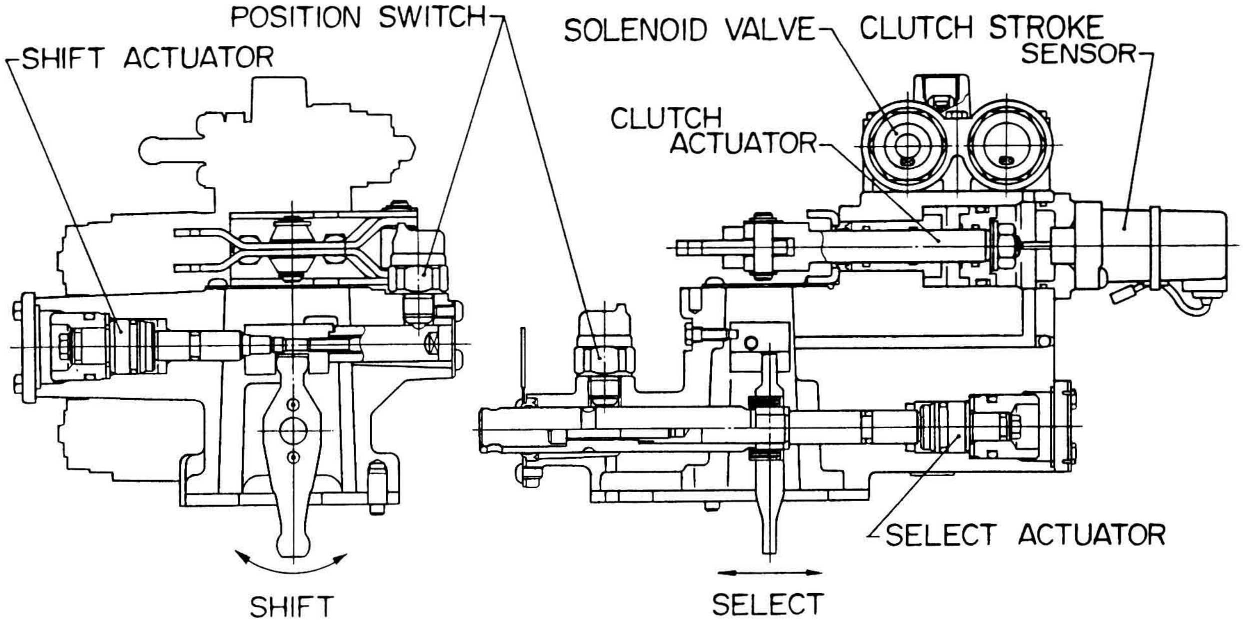

Fig.5 - Clutch and transmission actuator unit

open and close in high frequency, of these valves to ensure smooth clutch engagement. The ECU feeds back stroke sensor signal, recognizing the status of partial clutch engagement and determining the on/off ratio of the solenoid valves required to get actual speed of the clutch actuator.

The transmission actuator consists of a shift cylinder and a select cylinder which cross at the right angle. After the shift lever (its fulcrum on the select piston rod) is actuated to the shift rod of the newly shifting gear, the shift piston operates the shift lever to move the shift rod to complete gear shifting. The shift cylinder and select cylinder are of a 2-fluid chamber type, with each chamber provided with a 3-port solenoid valve (V5 & V6 for the select cylinder, and V7 & V8 for the shift cylinder) which switches the power source to the chamber and the chamber to the reservoir passages. Pistons are controlled by the combined operation of these solenoid valves. For instance, when both solenoid valves are operated between the power source and the chamber (in each cylinder), the pistons reach their central position - neutral position of shift actuator and 3rd/4th speed select position of select actuator. When one valve is opened between one chamber and the power source in one cylinder while the other valve is opened between the other oil chamber and the reservoir, pressurized fluid is supplied into that chamber to move the piston rod to the opposite side, thereby effecting either shift or select operation. The shift and select cylinders are each provided with a piston rod position detecting switch at each position. Through these switches the ECU detects the positions of the actuators and the completion of gear shift and select operation.

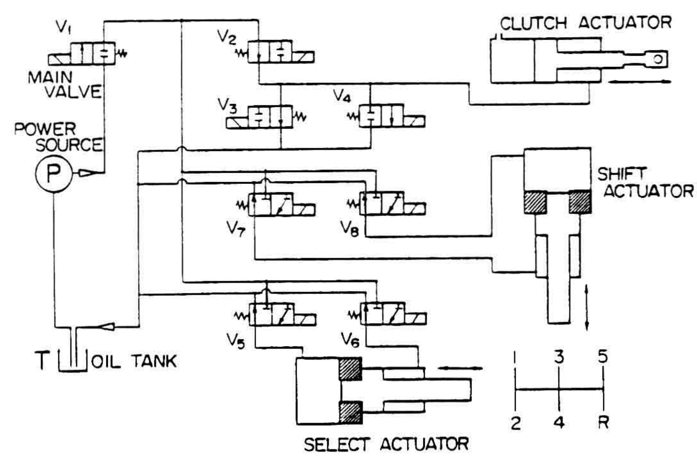

Fig.6 - Fluid circuit of the actuator unit

SENSORS

ECU receives feedback from each actuator and detects the driver's intention and vehicle operating conditions from each sensor. (Fig.7)

(1) Selector lever switch

The selector lever is of the same type as a manual transmission's floor shift change lever, with position switches corresponding to each lever position provided. The ECU uses this signal as the primary information to choose between full-automatic and semi-automatic (power shift plus automatic clutch, which is hereafter called "manual shift") in accordance with the driver's operation. H-type shift pattern has been chosen to ensure a sporty feeling of manual shift.

(2) Accelerator pedal sensor
The engine and accelerator pedal are not connected mechanically. An accelerator pedal sensor (that is, a potentiometer) and two switches attached to the accelerator pedal detect pedal stroke, and the ECU operates the throttle actuator of the carburetor (or the injection pump) based on that signal, thereby controlling automatic gear change, automatic clutch, etc. The switches detect the released (Idle) and full stroke (WOT) positions of the accelerator pedal. With the resistance value of the potentiometer at the working position of that switch used as a standard, the resistance of the accelerator pedal sensor in voltage signal form is read through an AD converter.
(3) Engine speed sensor
With the ignition pulse (in case of a gasoline engine) or injection pump gear speed pulse (obtainable by magnet pick-up in the case of a diesel engine) detected, engine revolution is sensed by digitally computing the pulse frequency, which is mainly used as a clutch control parameter.
(4) Car speed sensor
With the speedometer reed switch pulse signal detected, the car speed is obtained by digitally computing the pulse frequency and is mainly used for the determination of shift timing in case of automatic gear change.
(5) Input shaft speed sensor
Transmission input shaft speed is obtained by digitally computing the pulse frequency generated by a magnet pick-up attached to the gear box. The input shaft speed sensor is mainly a back-up system for the car speed sensor. It diagnoses whether the car speed sensing is functioning normally. Should malfunctioning be detected, the sensor takes over the function of the car speed sensor to ensure safe operation.
(6) Water temperature
In cold operation the sensor senses coolant temperature to determine optimum shift timing for compensation of power.
(7) Clutch stroke sensor
Piston position is detected by means of a stroke sensor (a potentiometer) mounted on the clutch actuator piston shaft, and the clutch actuator operation is fed back to the ECU.
(8) Gear Position switch
Position of the shift and select actuators are fed back to the ECU by means of three position switches mounted on each actuator cylinder.
(9) Throttle switch
This switch is a throttle actuator limit switch which works in the full-closed (Idle) and full-open (WOT) positions of the throttle valve (or the pump lever). The ECU counts the number of driving pulses of the stepper motor from the idle position to determine the throttle valve opening accordingly.
(10) Other sensors
There are other sensors which are not directly related to automatic transmission controls. They input the following data to the ECU.
a. Battery voltage
   To compensate stepper motor driving torque.
b. Cruise control switch
   Automatic constant speed control by the ECU.
c. Air conditioner switch
   Idling speed control as engine load increases and power compensation.
d. Head lamp switch
   Idling speed control as engine load increases.
e. Brake switch
   Cruise control release signal and control of Hill Starting Aid (HSA).

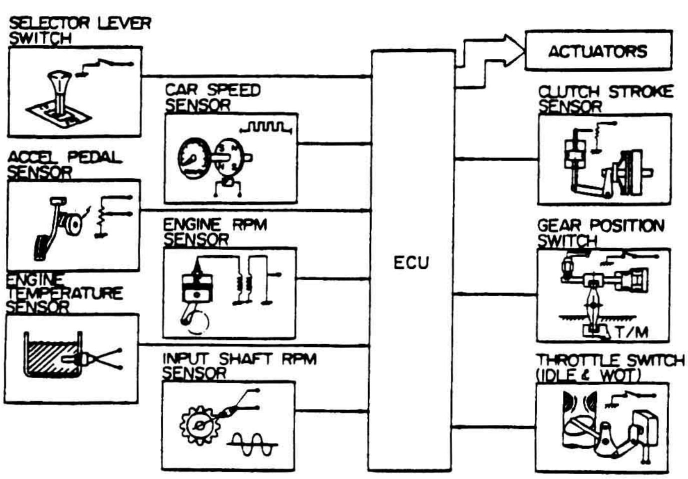

Fig.7 - Sensors

ELECTRONIC CONTROL UNIT (ECU)

FIG.8 SHOWS a front view and a printed circuit of the ECU which was designed and manufactured by Fujitsu Ltd. And the block diagram of the ECU is shown in Fig.9. The function of each part of the ECU will be outlined in accordance with the block diagram.
(1) Power unit
The power unit regulates the voltage supplied to IC and has other functions including breaking of overvoltage, detection of low voltage, power ON reset, and detection of abnormal program running.
(2) CPU
The CPU is a 8-bit microprocessor with 8K-byte ROM and 192-byte RAM, of which 64 bytes are non-volatile.
(3) Pulse signal conditioner
Pulse input, with its waveform rectified, is directly connected with a time interval measurable interrupt port of the CPU.
(4) Analog signal input circuit
The AD converter is of a sequential comparison type with a capacity of 8 bits.
(5) Contact point signal input circuit
A level shifter (a diode) is used to make up for ground potential because contact signal is grounded to the vehicle body. And the circulating current is secured for the stability of contact resistance.
(6) Stepper motor drive circuit
The stepper motor is of 4-phase type and driven 2-phase excitation.
(7) Solenoid valve drive circuit
The solenoid valves are actuated by Darlington

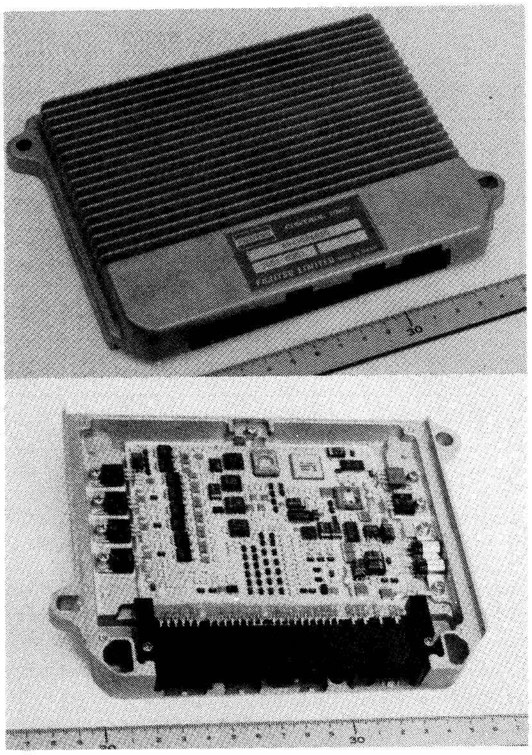

Fig.8 - ECU

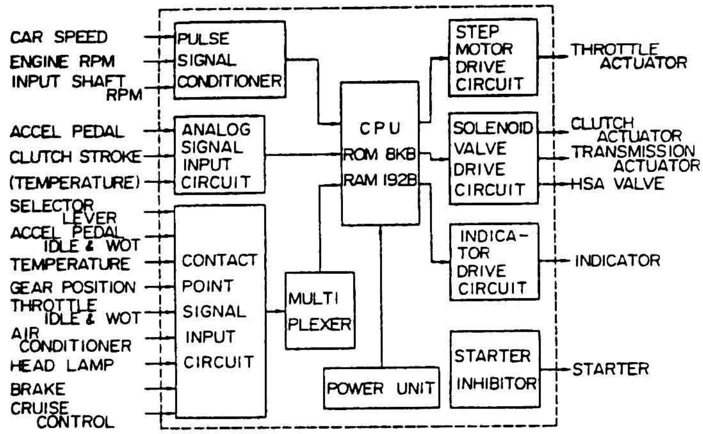

Fig.9 - Block diagram of the ECU

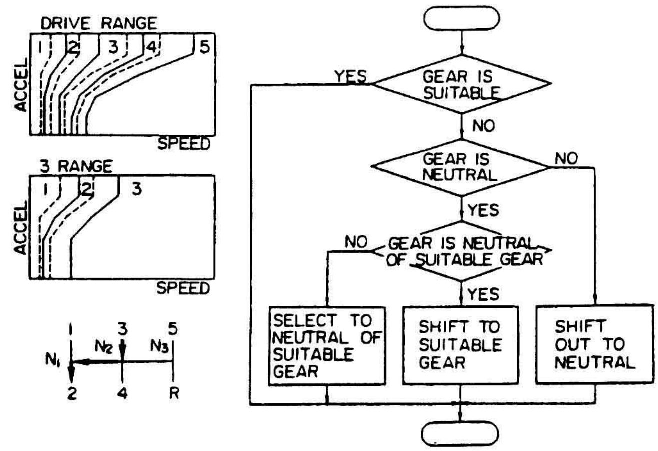

Fig.10 - Control flow (Gear change)

transistors directly at the output ports of the CPU.

(8) Indicator drive circuit

The indicator, installed in the instrument panel, indicates selector lever position and operating gear position, based on the signal received from the ECU. The drive signal to indicator is in serial mode of 16 bits.

(9) Starter inhibitor

For the safety of the automatic transmission, a safety circuit is provided so that the starter may not work unless the gear is in neutral position.

GEAR CHANGE

WITH THE SELECTOR LEVER set either in the drive (D) range or in the power (3) range, the ECU senses the required vehicle speed for gear change, in the manner of shift map searching shown in Fig.10, from the stroke of the accelerator pedal, and compares it with the actual vehicle speed, thereby automatically shifting up or down vehicle speed as required. Programming is done so that automatic 5-speed shift (1st to 5th) and 3-speed shift (1st to 3rd) are available in the D-range and the 3-range, respectively.

The selector lever is of the same type as the floor shift of a 4-speed manual transmission which features ease of operation and a sporty feeling of response. (Fig.11) During a drive, the ECT can be used as a powershift transmission with an automatic clutch, selecting 1st gear when the selector lever set in the 1-range, 2nd in the 2-range, 3rd in the 3-range (24 Km/h or higher), and 4th in the D-range (30 Km/h or higher; 5th for 45 Km/h or higher).

The ECU always monitors the driver's selector lever operation and selects a suitable gear for the driver's intention and driving condition. Should the operating gear is not suitable, the ECU controls the transmission actuator for gear change. As the flowchart shows in Fig.10, when the running gear is not identical with the optimum gear, the gear is shifted out to the neutral position, set in the neutral position of suitable gear, and finally shifted into optimum gear position.

ANALYSIS OF THE DRIVER'S CLUTCH OPERATION

AUTOMATIC CLUTCH CONTROL must be programmed simulating actual operating conditions. A driver operates a clutch pedal as traffic conditions demand, and a wide variety of actions are observed. To establish a multi-variable control strategy to determine clutch engaging speed from these situation parameters, experienced drivers' clutch operation patterns have been collected and analyzed as follows (Fig.12);

(1) Clutch engaging operation

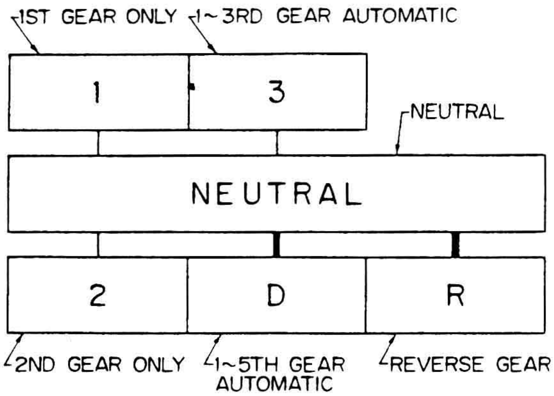

Fig.11 - Shift pattern

		CLUTCH ENGAGE SPEED		
GEAR POSITION		LOW	(↗)	HIGH
VEHICLE SPEED		LOW	(↗)	HIGH
ACCEL PEDAL		IDLE	(↗)	WOT
ENGINE RPM	PROPORTIONING TO CLUTCH TORQUE	LOW (STOP)	EQUAL (CONTINUE TO ENGAGE)	HIGH
	DIFFERENTIAL (INCREASE)	SMALL	(↗)	BIG
	DIFFERENTIAL (DECREASE)	BIG	(VERY SMALL ACTUATION)	SMALL
CLUTCH STROKE		DISENGAGE	(↘)	ENGAGE

Fig.12 - Parameters of clutch engagement

a. Relationship with gear position:
Speed at which clutch engages is in inverse proportion to the gear ratio.

b. Relationship with vehicle speed:
Speed at which clutch engages is proportionate to vehicle speed. As high gears are used while running at high speed, the use of gear position as a parameter is considered appropriate except for low speed running or start at 1st, 2nd and/or reverse gears. When starting from 1st, 2nd or reverse gear (Vehicle speed is almost zero) the clutch is usually half engaged at first, but in high speed running, the gears are not in that position.

c. Relationship with accelerator pedal:
Speed at which clutch engages is proportionate to the stroke of the accelerator pedal. When starting a vehicle, particularly when moving a vehicle only a few meters as seen in parking a vehicle, vehicle speed is controlled with the clutch partially engaged. The accelerator pedal is lightly depressed on in accordance with the clutch conditions.

d. Relationship with engine speed:

i) Speed at which clutch engages is proportionate to engine speed acceleration. This relationship is identical with the relationship with accelerator pedal, the only difference being that the accelerator pedal has a feed-forward effect, whereas the engine speed has a feed-back effect.

ii) When engine speed declines, speed at which clutch engages is very low or may possibly become zero.

iii) Minimum engine speed for its smooth running varies in proportion to clutch torque. Unless the actual engine speed is higher than the minimum speed, the clutch cannot be engaged any further. In other words, it is needed to obtain engine speed which can give rise to sufficient engine torque to meet clutch torque.

e. Relationship with clutch release stroke:
Speed at which clutch engages varies directly according to the clutch pedal stroke. The clutch pedal is stroked most quickly in the zero clutch torque range - from clutch disengaged position to the beginning of partial clutch engagement, and becomes slow in the partial engagement range, in inverse proportion to a rise in clutch torque.

f. Effect of road grade, payload, and driver's intention to accelerate:
All these factors, contributory to quick clutch engagement, are reflected on the stroke of the accelerator pedal depressed by the driver.

g. Engine brake:
In most cases of shifting down for engine brake, the clutch is engaged quickly, in spite of the accelerator pedal not being depressed.

(2) Clutch disengagement
The clutch disengages quickly irrespective of the parameters above.

AUTOMATIC CLUTCH CONTROL PROGRAMS

THE FOLLOWING THREE PROGRAMS have been formulated to put into practice a control strategy that covers all kinds of vehicle operations - selector lever operation, accelerator pedal depression/release, etc. - the driver may conduct in various drive situations (Fig.13);

1. A program which determines clutch control parameters representing clutch operations (engagement & disengagement), clutch operating speed, and travel of the release bearing (in case that the clutch must be held partially engaged).
2. A program which determines a drive parameter (pulse width modulation of chopping control) for clutch actuator solenoid valves (V1, V2, V3, & V4) based on the information supplied and feedback from the clutch stroke sensor.
3. A program which actuates the solenoid valves (V1, V2, V3, & V4) using the drive parameter supplied.

CLUTCH ENGAGEMENT CONTROL

FIG.14 SHOWS the programmed relationship between each situation parameter and clutch engagement. (Fig.15)

(1) Starting

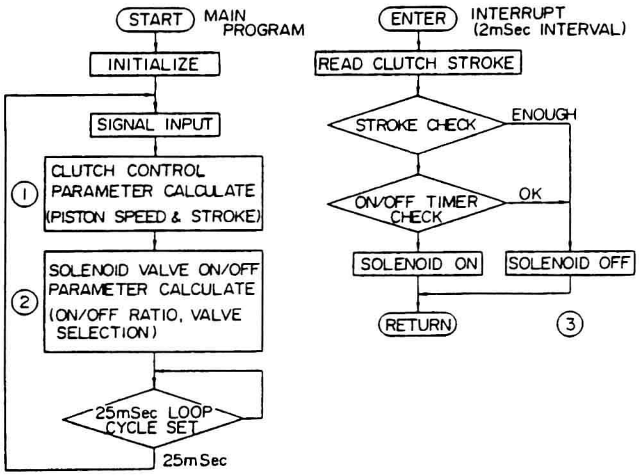

Fig.13 - Clutch control program

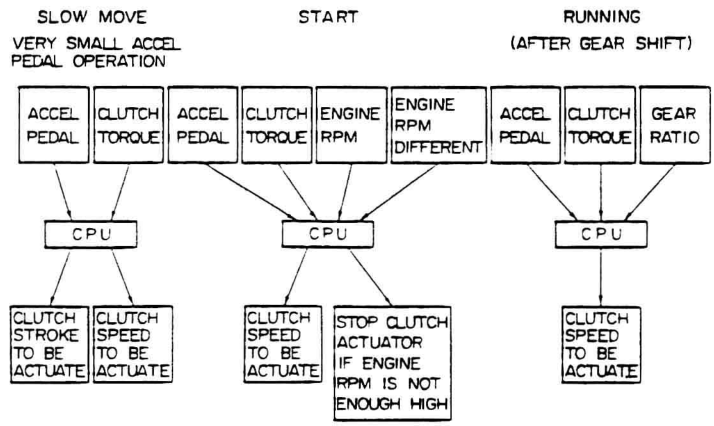

Fig.14 - Block diagram of clutch control

a. Engine start:
The starter can be operated only when the gear is in the neutral position. If the engine is not running with power "ON," the ECU will disengage the clutch. When engine speed has exceeded the specified R.P.M., the ECU engages the clutch gradually and the input shaft begins to turn. The clutch stroke sensor signal at this point is memorized as the starting-point of partial clutch engagement, which will serve as a standard for all controls afterwards. The memorized signal is stored in a non-volatile memory unit and continues to exist irrespective of power ON/OFF until it is replaced with a new signal. After the detection of the starting-point of partial clutch engagement, the ECU relieves fluid pressure from the clutch actuator to engage the clutch.
In response to the driver's selector lever operation the clutch is disengaged and gear is shifted accordingly. With the gear shifted, the ECU holds the clutch in a position just before the starting-point of partial engagement until the driver depresses the accelerator pedal.

b. Slow vehicle start:
When the driver depresses lightly the accelerator pedal (to the first quarter of full stroke or less), the ECU determines suitable release bearing travel (i.e. partial clutch engagement) according to the accelerator pedal stroke and controls the relief valves of the clutch actuator untill the feedback from the clutch stroke sensor becomes equal to the value determined. Then the ECU keeps the relief valves closed to hold the clutch partially engaged. On the other hand, the ECU determines suitable throttle valve opening according to the accelerator pedal stroke, too. And the ECU drives the stepper motor to open as determined.

c. Vehicle start:
In response to the driver's further depression of the accelerator pedal (to more than the first quarter of full stroke), the ECU controls relief valves at the operating speed of the clutch actuator proportional to the accelerator pedal stroke. Simultaneously, the ECU opens the throttle valve by turning the throttle actuator by a decreased number of steps to meet the degrees of clutch engagement as long as the clutch remains partially engaged. When engine speed rises sharply, the opening ratio of chopping control of the relief valves is increased to accelerate clutch actuator operating speed. When engine speed declines, the opening ratio of chopping control is decreased to reduce clutch actuator operating speed. If engine torque compares poorly with clutch torque, engine speed drops, causing knocking, body vibration, and, in the worst case, engine stall. To prevent them, the ECU calculates the lowest minimum engine speed required from the clutch stroke and stops clutch engaging operation if actual engine speed is lower than the minimum speed. Clutch torque rises sharply as the clutch engages. To obtain a smooth clutch torque rising curve, clutch operating speed is reduced as required.

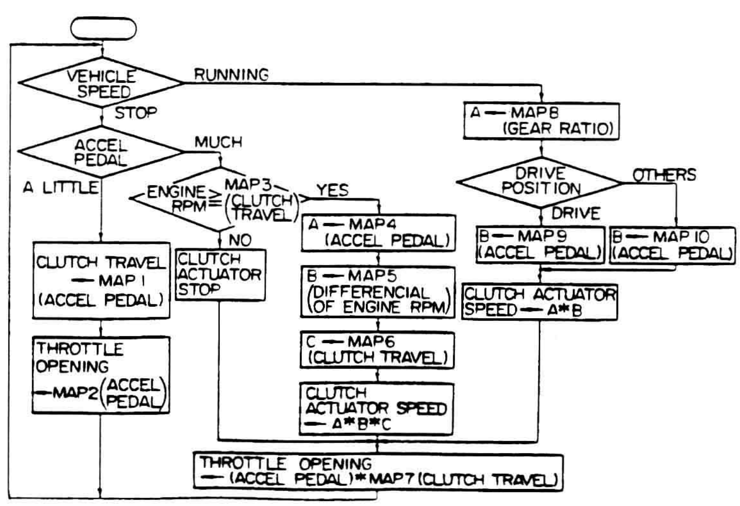

Fig.15 - Control flow (clutch engagement)

(2) After gear change
When engaging the clutch after gear shift, the ECU determines clutch actuator operating speed based on the shifted gear and the stroke of the accelerator pedal. In determination of clutch actuator operating speed, even in the case of same gear position and accelerator pedal stroke, the data for the D-range and those for other ranges are different, because of response requiered. The opening of the throttle valve is controlled, as in the case of start control, in accordance with clutch stroke so that engine racing can be prevented.

CLUTCH DISENGAGEMENT CONTROL

IN CASE OF GEAR CHANGE and when the accelerator pedal is released during driving at a lower vehicle speed than the speed set for each select position, the ECU disengages the clutch. The vehicle speed for clutch disengagement is set based on the use of each select position. A comparatively high vehicle speed (about 20 Km/hour) is set for the D-range, and a comparatively low vehicle speed (about 10 Km/hour) for the other ranges considering the effect of engine brake.

HILL STARTING AID. (HSA)

ONE OF THE MAJOR REASONS why users prefer a torque converter type automatic transmission is ease of starting on uphill. When starting on a steep hill, however, for the ECT with only an electronically controlled dry clutch, it was difficult to operate the brake and the accelerator pedal timely and properly. HSA has been added to make uphill start easier.

HSA uses a solenoid one way valve set in the brake fluid line, retaining the foot brake-produced braking fluid pressure while the vehicle stops on an uphill and releasing at start, thus preventing the vehicle from sliding backwards. This solenoid-operated valve is controlled by the ECU. To be more specific, as soon as vehicle stop has been detected, the ECU lets electric current flow to the solenoid to prevent brake fluid's flowing return from the wheel cylinder into the master cylinder even after the brake pedal is released, thereby holding the vehicle at a stop. As the accelerator pedal depressed, the ECU begins to start the vehicle, the clutch reaches the starting point for partial engagement, a flow of current to the solenoid is broken to release the breaking fluid pressure.

ROAD PERFORMANCE TESTS

ROAD PERFORMANCE of ECT sample models will be summarized based on the test data. (Fig.18-21)
(1) Time lag from accelerator pedal operation to actual vehicle start was 0.5 - 1.0 second. The test results have revealed the appropriateness of the control strategy - good start performance which matches the driver's accelerator pedal operation and sufficient response to the driver's intention even to any unusual accelerator pedal operation during clutch control.

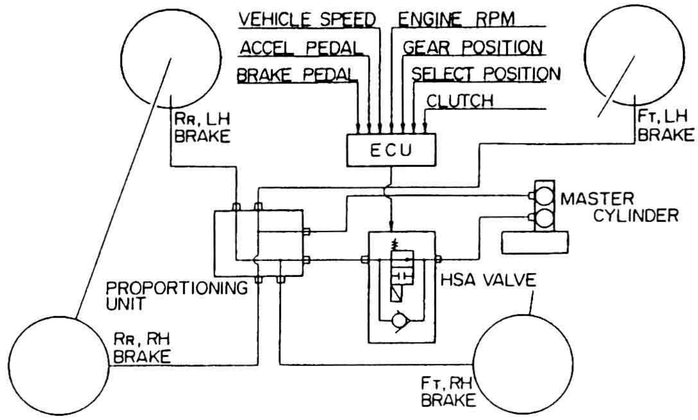

Fig.16 - HSA system block diagram

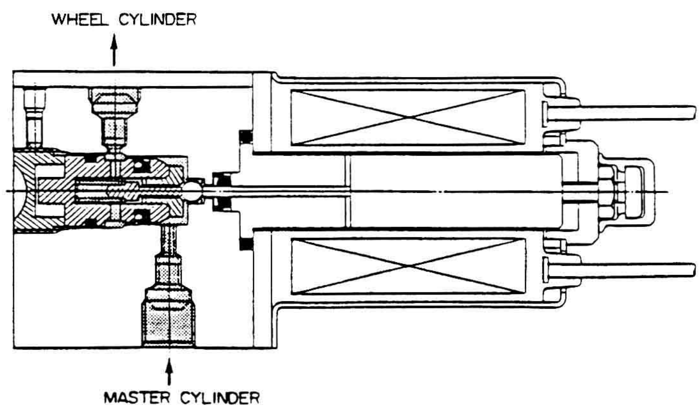

Fig.17 - HSA - solenoid one way valve

(2) Coasting during shift up, response to kickdown and manual shift are 0.6 - 1.0 sec. Therefore, there is no problem in the 2nd and higher gear running. Coasting during a shift from the 1st to 2nd was felt by almost all test passengers on the test track, but less complained on real city road running. It seems therefore that a coasting feel changes depending on the drive environment. Shift shock was lighter than in case of a manual transmission. Kickdown and manual shift down shocks were lighter than in case of a conventional automatic transmission.
(3) At a short-distance movement, which has been discussed very troublesome in the case of a dry clutch electronic control, an ECT got rather good result, though smoothness was inferior to a torque converter.

FUEL CONSUMPTION TESTS

SHOWN IN Fig.22 are the results of comparative fuel economy tests with three types of transmission installed in same vehicle model (Isuzu ASKA, J-car notch-back, FWD, 2,000 cc, with 1,350 Kg G.V.W.). The test track used was 3.44 Km in overall length, provided with 11 stopping/starting points (including two slopes,

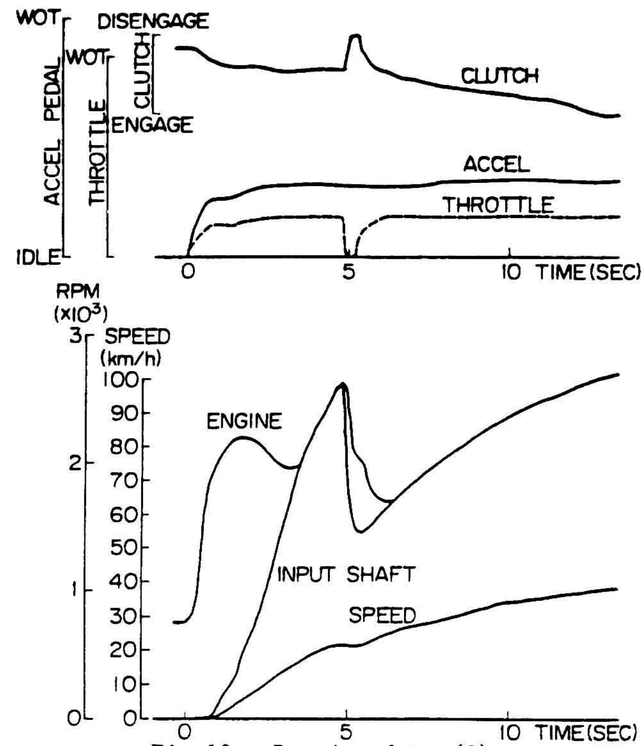

Fig.19 - Running data (2)
Standing start

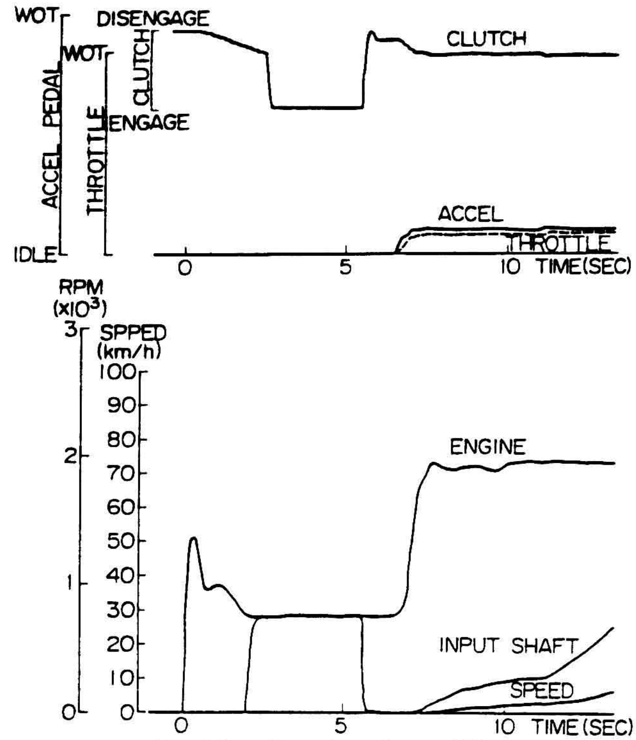

Fig.18 - Running data (1)
Engine run and parking

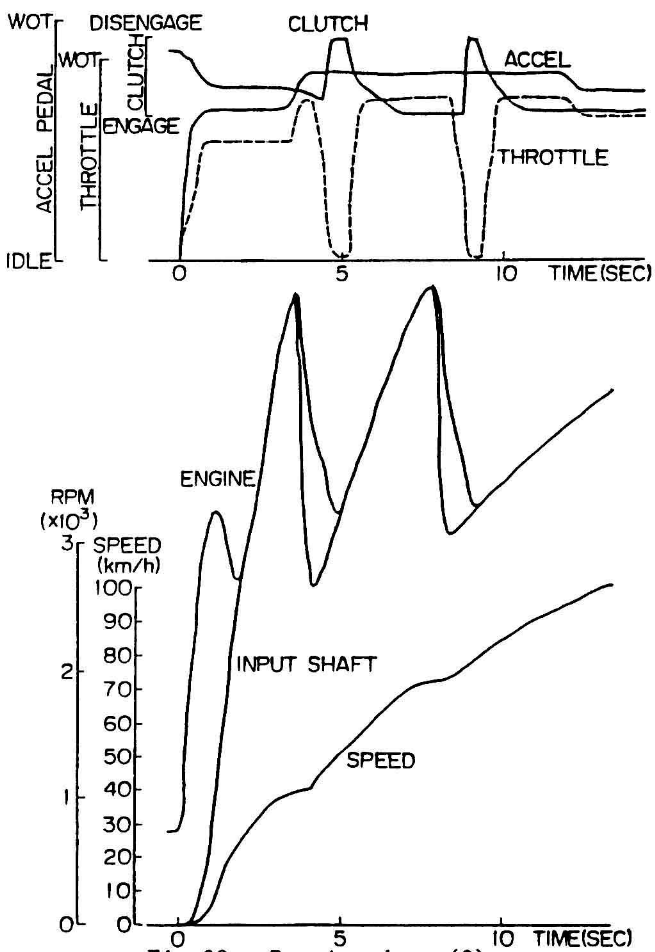

Fig.20 - Running data (3)
Radical start

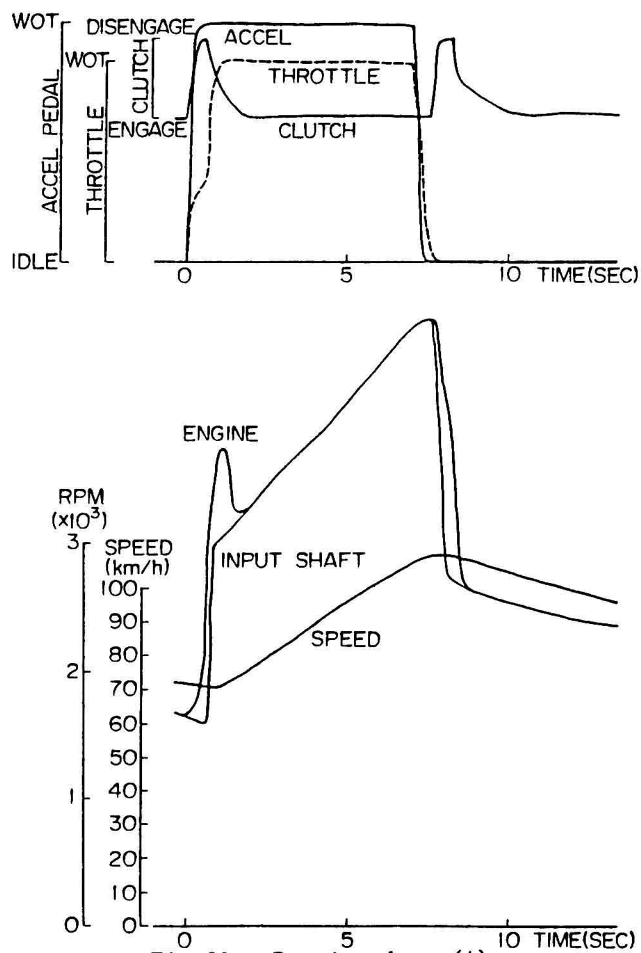

Fig.21 - Running data (4)
Kick down

5% and 10%) and 11 corners. Sample vehicles followed a pace car which ran on a Japanese in-city stop-and-go drive pattern. Six test drivers were grouped as follows;
Group A: 3 drivers with 10 or more years' experience.
Group B: 3 drivers with up to 1 year's experience including two women.
Each test driver drove three sample cars twice.
As the data suggest, even in the case of an M/T of which fuel economy is generally regarded as good, fuel consumption rate in medium & low speed operation varied significantly with the drivers. A great difference was seen between experienced drivers and beginners; beginners experienced worse fuel economy than the level of an A/T. And the results of the first and second tests with the same sample units were considerably different. In contrast, an A/T showed no noticeable gap between experienced drivers and beginners, and there was little variation in test results among the samples tested.
With regard to an ECT, experienced driver's average fuel economy was at the level of an M/T and beginner's attainments were on the total average level of an M/T, thus total average fuel economy of an ECT was better than that of an M/T. Test results variation was smaller than these of an M/T and an A/T.

High-speed-running fuel economy tests were not conducted, because fuel consumption rates of an ECT is theoretically equal to that of an M/T.

SUMMARY

A 370,000 KM CUMULATIVE TEST - durability test, special environmental tests including cold/hot area drive and strong electro-magnetic field test, and user clinic - has proven that the ECT has attained the targeted "driveability" and "enjoyability" while maintaining good fuel economy, hence, a high market acceptability.

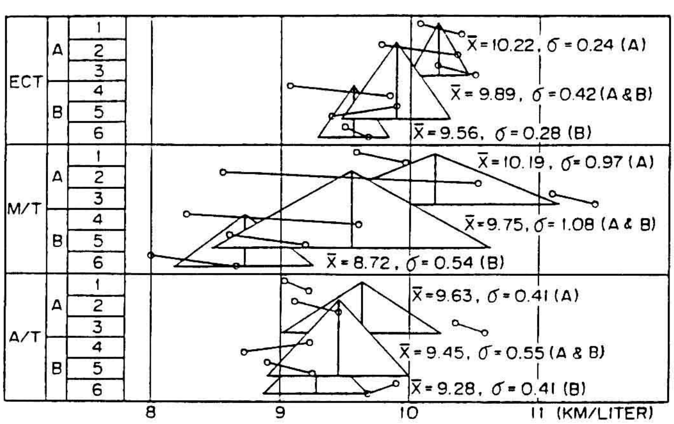

Fig.22 - Fuel consumption test data

Note: The central axis of each triangle shows the average and the base shows the standard deviation ($-\sigma$ to $+\sigma$).

Since characteristics of this system mainly depend on software, so this system is so flexible that applications to trucks and buses would be possible by simply re-programing software programs and changing some actuators.

840441

Flame Arrival Sensing Fast Response Double Closed Loop Engine Management

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ABSTRACT

The crank position related arrival time of the flame front at a flame front arrival sensor, positioned in the endgas area of the combustion chamber, controls cycle by cycle the best ignition timing. The jitter amplitude in flame front arrivals at the same flame front sensor (FFS) controls the A/F and/or EGR ratio towards target values.
A double closed loop control (DCL) is realized which controls simultaneously the charge composition for minimum brake specific fuel consumption (BSFC) and the co-related ignition timing over the speed load range, considering all varying parameters like octane requirement increase (ORI), all interesting temperatures, as exhaust valve, piston deck, engine oil and water etc., fuel variables as CHO ratio, MON, density, viscosity, ambient conditions as humidity and altitude, general engine conditions as spark plug erosion, etc., utilizing basically only one extra sensor and control means. Still the same means serve for preknock detecting and control.

1. INTRODUCTION
The spark ignited internal combustion engine (SIICE) has always been dependent upon a correct air and fuel (A/F) metering and a corresponding speed, load and fresh charge composition depending spark advance. The vital importance of the spark advance settings in dependence of load and speed has been explicitely and theoretically demonstrated by several authors, namely H. List (1) in 1939.

Preset spark advance curves, realized mostly in the distributor, and preset carburettor or fuel injection systems, providing the metering of fuel to the air, have for nearly a century governed these two parameters throughout the wide operating ranges required from the engine by the user. In recent years, a corresponding mapping attempt is realized electronically, mainly by storing the required mapping information into ROM s, PROM s, EPROM s etc. Further refinement has been realized with the use of micro processors (μ P), able to interpolate and to utilize the input of varying parameters like air temperature, engine temperatures, knock sensor signals, and, if required, O_2 sensors. Nevertheless, even the best but fixed matrix type control is right only for very special operating conditions as existent during mapping on the engine dynamometer. A variation in combustion chamber deposit formation and surface temperatures, fuel density, fuel quality, fuel composition, air humidity or engine wear, could not easily be considered in a realistic and automatically governed setting.

2. STATE OF THE ART

The approach towards a closed loop control, respectively optimization of the parameters, influencing the operating conditions of spark ignited engines by monitoring the spark ignited engine itself, has been aimed for many years.

Reported attempts date back to 1932 from Charles Walker (2). Since 1951 Draper and Li (2") restarted intensive research; many other efforts are documented by P.H. Schweitzer in several papers (3,4,5,6) by H. Zimmermann (7), M. Zechnall (8), A. Lampert (9), J.G. Rivard (10), Bosch (11), Glaser and Powell (12) for example.

The achieved response time was relatively long due to the mostly utilized "try and seek" steps, and has been quoted with 5 to 15 seconds. A fast response time strategy to achieve minimum BSFC and/or minimum emissions at lean or EGR diluted charges has not been achieved.

Successively R. Latsch (12,13) described a method of controlling the ignition timing. Here, a direct measurement is utilized, thus avoiding the try and seek method. This proposed method compares the measured delay after TDC at which peak pressure occurs in the combustion chamber, with a reference delay and adjusting the ignition timing in function of any difference between the compared delays. Piezoelectric pressure pick ups or ion current measurement provided the input signal to be evaluated in respect of crankshaft angular position.

Similar approaches are described by T. Ma (15), Alfa Romeo (16) and E. Ford (17), where flame travel times are utilized to control ignition timing and /or air fuel ratios.

It also has been thought, that a correction of the reference crank position value in function of engine speed and load, fuel/air mixture, temperature and inlet manifold pressure would be necessary. This may explain why further efforts in these closed loop control attempts have been abondoned, often in favour of the attempted development of "leaning" λ P based engine management. There remain some doubts about what and how to teach the chips.

3. REASONS FOR AN IMPROVED CLOSED LOOP APPROACH

Combustion engine development made tremendous progress in the fields of increased efficiency and reduced pollution. Namely by new combustion chamber design, as for example fast and lean burn concepts (18,19) and efforts to reduce friction, it became more and more obvious that the limiting factors are constancy in best setting, despite variation of parameters influencing flame propagation, as for instance: chamber deposit formation, instantaneous combustion chamber wall surface temperature (including piston surface and exhaust valve temperature), fuel quality (RON, MON, sensitivity, etc.), ambient air temperature, pressure, humidity, fuel density, fuel composition (C,H,O, ratio), spark plug deterioration (electrode wear), carburettor metering drift, EGR valve alteration, deterioration, aging of engine and engine accessories.

Even if all variables could be measured easily and rapidly enough, it would require endless time to simulate, measure and map all this information, store it and adjust the carburation and the spark event accordingly for each engine type.

As a result even the latest micro processor controlled engine management can only by chance, from time to time, give, for a few consecutive operating cycles, the optimum setting relative to the instantaneous operating condition.

The worst is, that for future fast and lean burn engines, the spark advance requirement at constant load and speed increases with increased charge dilution, respectively increased throttle plate opening or increased manifold pressure.

Therefore the conventional spark timing control strategy no longer satisfies the requirements of a thermodynamically optimized part load operation.

In other words, the requirement for a fast lean burn engine is a spark advance taking into account the instantaneous composition of the charge more than the manifold pressure.

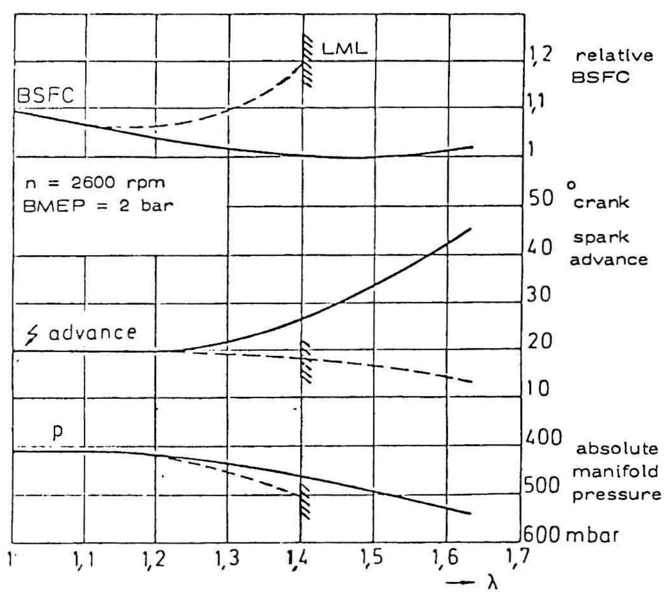

Fig. 1
Lean burn engine spark advance variation over air/fuel ratio at constant load and speed, and incidence on relative fuel consumption.

——— manual or target closed loop setting
- - - - manifold pressure controlled spark advance
LML = lean misfire limit