MEMS (MODULAR ENGINE MANAGEMENT SYSTEM)

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SYNOPSIS

MEMS is a new generation engine management system for fuel injected engines. The system control unit is modular in construction to cover various combinations of Programmed Ignition, Singlepoint, and Multipoint Fuel Injection. The system was designed and developed at Rover, and is in volume production on the new Rover 214, 414 and Metro GTi, all fitted with the new 'K' series engine, and on Montego.

CONTENTS:

1. Introduction

In 1985 Rover took the decision to design and develop in house its own engine management system for fuel injected engines. The result is MEMS which is a combination of Electronic Fuel Injection and Programmed Ignition in a single underbonnet control unit. The Rover 214 system block diagram is shown in Figure 1.

MEMS is formatted to provide expansion for future engine developments. This paper details the concepts put into the design and briefly describes the results before examining the real benefits to Rover of its unique product.

MEMS ECU's are designed at Rover, in conjunction with Motorola AIEG, the ECU manufacturers. Software is written in house at Rover.

2. Product Philosophy

The following philosophy guided the development of MEMS:-

Product leadtime two years. This led to the decision to take the design of the ECU in house and use an external manufacturer. It is our experience that this methodology optimises leadtimes.

Cost to be lower than equivalent bought out system. Again this led to the decision for in house design especially when coupled with the need for design flexibility.

Quality to be best in class. This was controlled by the design and the choice of supplier.

Product to be supported with advanced tuning aid. This gives online tune changes, tune swapping, high speed data logging and the ability to release a tune directly from the tuning aid. All these features had a significant impact on reducing product leadtimes.

Modular Design. This was to cover a wide range of specifications from base open loop TBi to closed loop sequential MPi with boost control of turbo charging within one basic product.

3. System Hardware

The Modular approach. To cater for various combinations of vehicle requirements, and to achieve the aim of improved quality, with reduced cost the MEMS system hardware was integrated as much as possible: A single base ECU (Electronic Control Unit) design was used with 11 add-on internal modules. Table 1 shows the production options available and those used to date. The only module options that are mutually exclusive are the choices of single, dual, or banked Injection. Within the limits of the matrix there is no need for hardware redesign, or retesting.

One ECU - Underbonnet. Previous EFI systems had two Engine Management ECU's, an Electronic Fuel Injection unit sited in the vehicle compartment, and a Programmed Ignition Control unit underbonnet. MEMS combined these functions into one underbonnet ECU near to the majority of the system components. This improved vehicle assembly and eliminated 25% of the system connections.

To operate underbonnet and keep the internal temperature below component limits of +125^0 C, low power consumption Field Effect Transistors were used on all outputs.

Designing for manufacture. The previous engine management system with two ECU's had a combined PCB area of 588 sq cm. Such a size would not package in the confined underbonnet area where mounting space is always at a premium. By using surface mounted components and a 4 layer PCB it was possible to reduce the PCB size by 54% to a manageable 272 sq cm. 92% of the ECU's components are automatically surface mounted, only power and some specialist components are not surface mounted. The use of rapid automatically assembled components removes many of the quality issues associated with leaded and hand assembly operations. Manufacturing costs were reduced with simpler parts storage and preparation prior to assembly, and increased ECU throughput.

Designing for testability. Testability was improved in ECU manufacture, vehicle assembly and service by designing into the MEMS ECU a diagnostic link. Serial communication can take place between the ECU's microprocessor and external computer based test equipment without breaking the connection between ECU and vehicle. The need for large ECU test rigs in manufacturing have been eliminated. "Burn in" rigs, previously used for 100% testing are not used in the MEMS manufacturing process. We chose instead to rely on the ECU's design integrity and more stringent functional testing via diagnostics.

Semi-automatic test stations have been added into the vehicle assembly track. When connected to the vehicle's diagnostic connector they identify the ECU and test all system sensors and switches. Any faults are printed out for use in rectification. They are also used to aid system fuel and idle "adjustment" settings.

Test and fault diagnosis in the dealer networks is done with Rover's computer based 'COBEST' and 'Microcheck' Service test equipment. These also access the vehicle system via the diagnostic link. Failed parts returned under warranty must be accompanied by a test report from one of these units. This technique is vital in reducing the number of ECU's wrongly returned as faulty.

The use of a non volatile EEPROM (Electrically Erasable Programmable Read Only Memory) in the MEMS ECU allows system faults, even if intermittent, to be recorded.

ECU Reliability. Two different prediction methods were used on the MEMS design:-

FITs (Failures In Time)
US Military-Handbook-217E

The FIT method. Failures In Time were seen as a more user friendly way of predicting ECU reliability. 1 FIT = 1 failure in 1 billion device hours of operation.

All suppliers were asked to supply a FIT number for each of their components, based on a predicted lifetime temperature/time profile of:-

40 hours at 125° C, 360 hours at 65° C and 8366 hours at 25° C.

MEMS had 1692 soldered joints. It was interesting to note that different manufacturers gave quite different soldered joint reliability figures. In one case the soldered joint failure rate was 46% higher than for all the components in the design, indicating how important manufacturing processes are in true reliability.

The Overall ECU FIT figure was 8241 FIT.

ECU failure rate per year was calculated as: 8241 x 600 hrs x 100%/(1E+9) = 0.49%

Reliability = 1 - failure rate: ECU Reliability Prediction = 100% - 0.49% = 99.5%

US Military Handbook-217E Adaption Method. MIL-HNBK-217E, although not an exact correlation to field reliability, provides a standard on which to base reliability design reviews. The MEMS study used Parts Stress Analysis.

Results:-

	FAILURES PER MILLION HOURS		
	+25°C	65°C	125°C
Total MEMS ECU	13.2	32.0	838.3
Highest failures:-			
Circuit board	1.5	8.3	169.6
Intel 8096 uP	0.9	4.0	112.7
Drive Circuit Hybrid	1.4	2.5	66.1
Knock Sensor Hybrid	1.1	2.3	63.6

Failure rate over the recommended temperature profile was calculated as;

Failures per million Hrs =(Failures per Million Hrs @ T°C)(Hrs @ T°C)/(Total Hrs)

Failures per million Hrs @ 25°C =13.2 x 8366/8766 = 9.6

65°C =32.0 x 360 / 8766 = 1.3

125°C =838.3 x 40 / 8766 = 3.8

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Total Failures per million Hrs =14.7

Percentage MEMS failure rate per year = 14.7 x (600hrs)(100%)/(1E+6) = 0.88%

Reliability = 1 - failure rate: ECU Reliability Prediction = 100% - 0.88% = 99.12%

Product Proving and Testing. The proving programme employed a comprehensive test matrix to examine the functionality, durability, and reliability of the MEMS system.

Laboratory DV (Design Validation) test matrix on a minimum of 39 'off tooled' production level ECU's covered; Functional, Humidity, Temperature, Dust, UV Light, Thermal Shock, Salt Spray, Contaminants, Mycological, Vibration, Rig Endurance, Stress to Failure, Thermal Cycle, and Electrostatic Discharge Testing.

An environmental test rig C&R (Confidence and Reliability) programme tested over 320 'off tooled' production level ECU's. Each ECU was thermally cycled under simulated vehicle load conditions for 600 hours to achieve at least a 99.5% statistical reliability, to an 80% confidence level.

An on-vehicle test programme, distributed over 25 vehicles, covering High Speed, Urban, Rough Road, and Pave achieved over 500,000 vehicle miles prior to product launch.

Vehicle EMC performance of MEMS was improved beyond the previous minimum pass level of 50v/m by using one of the ECU's four PCB layers as a ground plane.

4. Software Design.

A single chip microprocessor was used to minimise the cost of the ECU by obviating the need for external memory and associated port reconstruction components. An additional benefit of using on chip resources was shorter execution times - another key parameter in an Engine Management Controller.

The software is designed to provide a large number of features:-
These include Steady State and Transient Fuel Control, Ignition Control incorporating individual cylinder Knock avoidance, Idle Speed Control, Faulty Sensor Backup/Limp Home, End-of-Line Test at both the ECU manufacturer and the vehicle line and finally diagnostics for service technicians incorporating intermittent fault logging.

A complex design and a limited resource of 8K of ROM and 232 bytes of RAM, albeit in a 16 bit single chip Intel 8096, provided a very special challenge. It is clear that very tight control of code usage would be required, and to aid this the various features were allotted a proportion of the overall memory allocation. The initial and realised feature breakdown is shown in figure 2. As can be seen Fuel Control is the largest consumer of resource but surprisingly Idle Speed Control came second, taking as long to develop as the Fuel Control. Ignition Control was complex but required less space than the associated Knock Control.

The predicted figures bear comparison but were in error primarily in Ignition, Diagnostics and the Idle Speed Control area. The Tune area was also a minor casualty.

In order to meet the programme timing and the memory limitations the strategies were developed in very close conjunction with the customer. The customer in this case being our own Engines and Emissions departments. Having in house control of the software allowed for very rapid feedback and minimised the number of "official" links in the chain.
Specification development, customer liaison, testing and delivery of code was carried out by the same engineer to ensure very short communication links. This way of operating has stood the test of time and has been developed further on current designs.

Previously software had been designed on stand alone development systems. These projects were characterised by having a single specification for a particular model, or developments where the software was not planned to go into volume production. They were typically the responsibility of one engineer. MEMS was a radical change. MEMS software had to be developed by a team of people and for a mix of specifications over a wide range of models and engine variants. The decision was therefore taken to develop the software using a network of PCs. This enabled a database of software modules to be constructed and allowed all team members access to the latest code. The network approach is still in place today, the major change being that it has expanded from 4 workstations to 20.

A vital part of any engine management programme is the development of the Calibration or Tune. This process can be greatly enhanced by the use of portable computers. A major part of the MEMS development was the design of a tuning aid or PETA (Programmable Engine Tuning Aid). PETA enables the engineer to display and modify any of the tune parameters both on line and off line. There is capability to dynamically switch between tunes while the engine is running. Printouts of maps can be readily obtained, and even the final tune release comes from PETA and is integrated into the final mask in an automated fashion. This reduces the possibility of errors as well as being more efficient. The PETA project was a major development in its own right involving the production of 200K of code. The system is continually being enhanced and is fundamental to the successful development of any vehicle programme.

Control strategies A representation of the relationships between inputs and outputs is shown in Fig 3. The interconnect between the various blocks shows the desirability of having all the control functions handled by one microprocessor. The base designs that are currently in production employ the speed density method of air flow measurement. This places a greater overhead on the system in terms of computing power required but provides significant system cost savings by not requiring a mass air flow meter.

Validation. Software validation is an important part of any design/development process and is required to ensure that critical areas are closely scrutinised.The process employed on the first production MEMS units was that of formal design review including FMEA code walkthrough and peer scrutiny. This method has proved to be satisfactory with regard to the quality of the software produced but was very labour intensive. All future designs will include the above process but will also be presented to a third party validator with static code analysis being a minimum requirement.
Future areas of work include the use of formal methods for specification generation and consideration is also being given to dynamic analysis. The key is to get the design right at the specification phase and to use computers to automate the process of validation.

5. Product Feedback

ECU and system cost. The trade off between cost, quality and increased system functionality is always a popular subject in the Automotive Industry. However, improved functionality and quality do not always mean increased cost. MEMS ECU system costs were reduced by 46% with a combination of design integration and the use of a speed density, instead of the previous mass air flow system strategy.

ECU Reliability. Figure 4. shows the normalised warranty returns against vehicle build month for the MEMS ECU and the control units it replaced. Although it is early to make firm conclusions the initial MEMS ECU warranty results are encouraging. The results indicate the move down the classic 'new product' manufacturing learning curve, and that warranty returns have already been significantly reduced. Comparing the July/August 88 and July 89 returns we have an ECU warranty reduction of 40%.

Conclusions. As a result of the design and development efforts MEMS was launched in April '89 on the 2.0 litre Montego 'O' engine with multipoint fuel injection, in October '89 on the Rover 214, March '90 on Rover 414 and May '90 on the new Metro GTi. The three latter models all use the new Rover 'K16' engine with singlepoint injection. To date over 100,000 units are in customer use throughout the EEC. Figure 5. shows the benefits Rover has gained over the previous system in terms of warranty improvement, cost and ECU packaging size. The normalised figures show gains at 40%, 46% and 54% respectively. As a result of this success MEMS is now being targetted at future Rover products with developments to reduce emissions, minimise fuel consumption and to provide major engine feature enhancements. The experience gained in developing MEMS as a reliable, high quality product at a competitive cost is allowing expansion to greater levels of sophistication, leading to enhanced customer satisfaction with the Rover product.

6. Acknowledgments.

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THANK YOU.

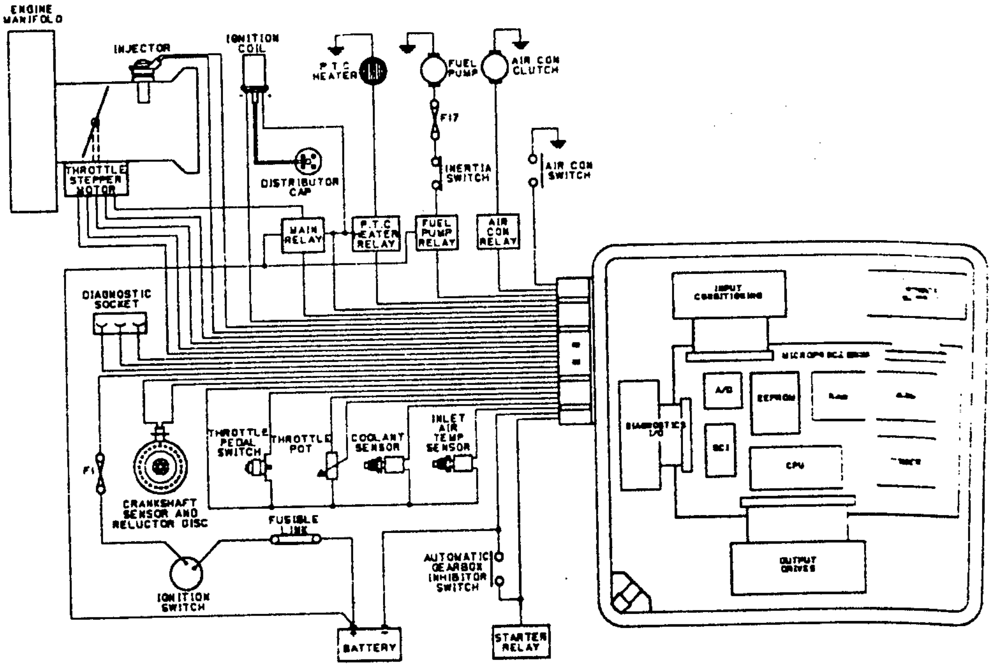

Fig.1 Rover 214 System Diagram

	OPTIONS	MONTEGO 2.0 EFi	MONTEGO 2.0 EFi AUTO.	ROVER 214		
1	BASE PROGRAMMED IGNITION	✓	✓	✓		
2	SINGLE TBi			✓		
3	SECOND TBi					
4	BANKED MPi	✓	✓			
5	AUTOMATIC TRANSMISSION		✓			
6	PULSE AIR					
7	EGR					
8	PURGE					
9	KNOCK	✓	✓			
10	AIR CONDITIONING	✓	✓	✓		
11	OXYGEN SENSOR					
12	SPARE OUTPUTS (4)					

Table 1 MEMS 1.2 Production Options used to Date

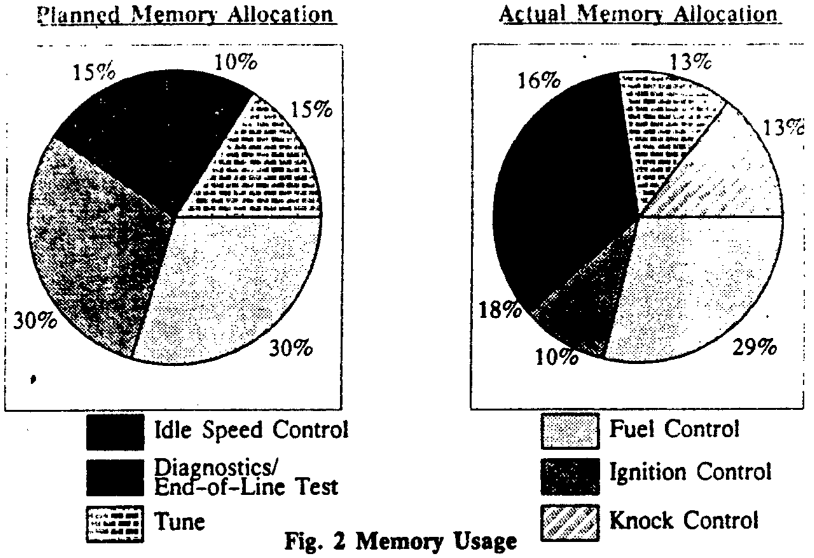

Fig. 2 Memory Usage

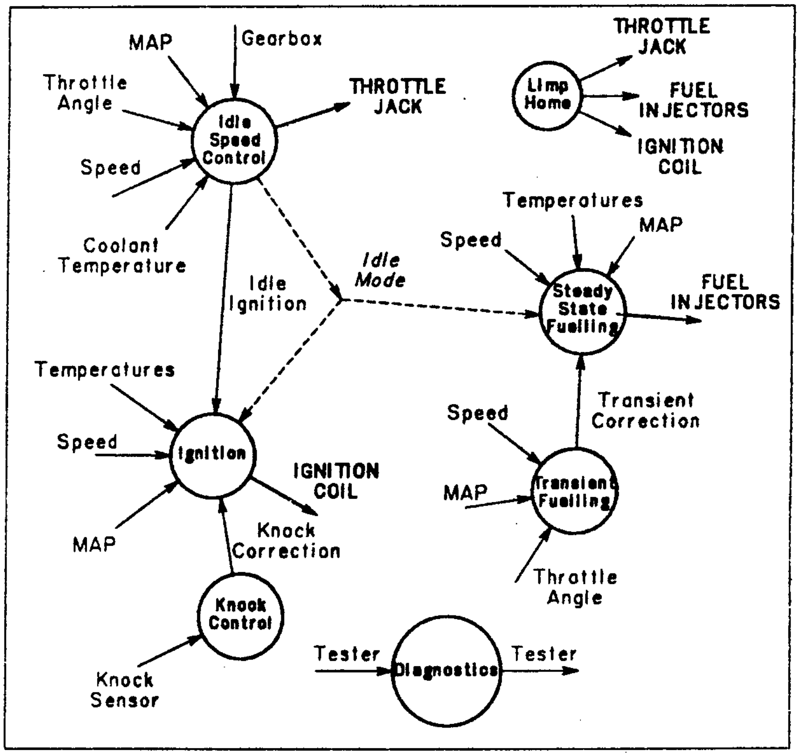

Fig. 3 Data Concept Diagram

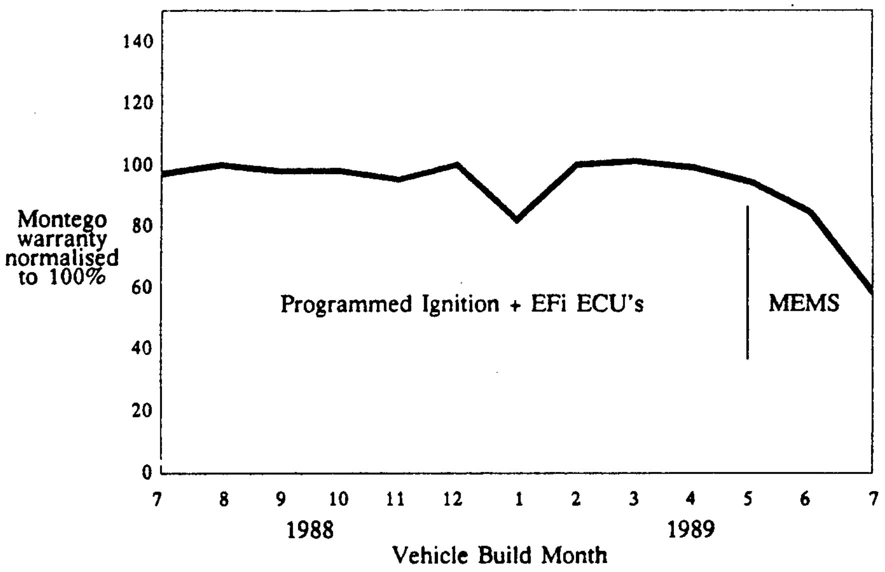

Fig. 4 Normalised Warranty Claims Montego Engine Management ECU's

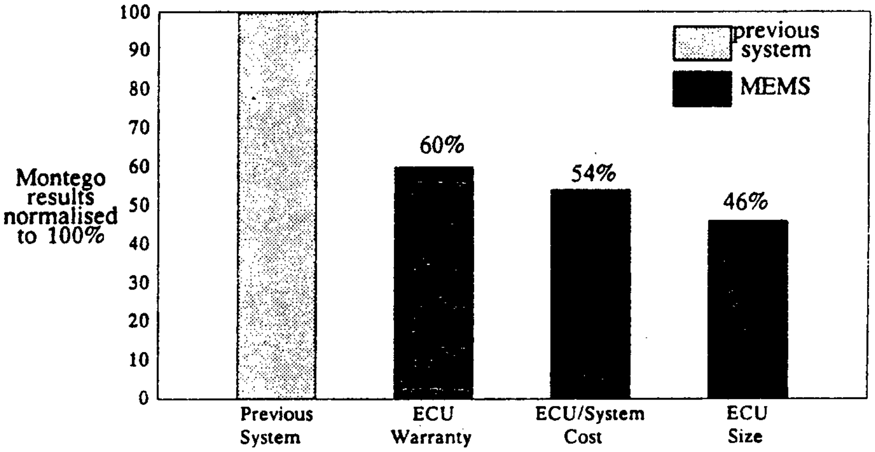

Fig. 5 Histogram of Warranty, Cost and Size Improvements Achieved on Montego with MEMS.