

3 A80

THE DESIGN OF A MECHANICAL DRIVER

P.J. Pryor

January 1988

Submitted to the University of Cape Town
in partial fulfilment of the requirements
for the degree of Master of Science in
Engineering.

The University of Cape Town has been given
the right to reproduce this thesis in whole
or in part. Copyright held by the author.

The copyright of this thesis vests in the author. No quotation from it or information derived from it is to be published without full acknowledgement of the source. The thesis is to be used for private study or non-commercial research purposes only.

Published by the University of Cape Town (UCT) in terms of the non-exclusive license granted to UCT by the author.

(1)

I, Paul John Pryor submit this thesis in partial fulfilment of the requirements for the degree of Master of Science in Engineering. I claim that this is my original work and that it has not been submitted in this or a similar form for a degree at any University.

SIGNED:

Signed by candidate

ABSTRACT

This report describes the design of a mechanical driver for use in the testing of vehicles on a rolling road dynamometer by the Energy Research Institute (ERI) at the University of Cape Town.

Many vehicle tests involve using driving cycles which tend to be long and repetitive. Consequently, the driver finds it boring and difficult to repeat a specific driving pattern within the required tolerance. One solution to this is the use of a mechanical driver, where the vehicle being tested is "driven" mechanically and controlled by a computer. The main objective of this project was to design a system that would return accurate and repeatable results when testing vehicles for fuel consumption, emissions, speeds etc.

Mechanical drivers have been used by many European car companies for exhaust emission control tests where vehicles have to undergo a fixed driving pattern to satisfy regulations. Volkswagen of West Germany and Ford Motor Company of America have published papers on systems which they have built for various development programmes. The Volkswagen driver was designed for use in vehicles with an automatic transmission and was installed in the place of the front passenger's seat. The Ford driver on the other hand could "drive" the vehicle as well as shift the transmission if the vehicle was equipped with a standard transmission. Other companies such as Carl Schenck, a West German company and Britain's Motor Industry Research Association have designed and built mechanical drivers. These are sold to motor manufacturers on a customer-contract basis.

An initial mechanical driver was designed based on the equipment and supplies available to the ERI. This was done to keep costs as low as possible. A prototype was built according to this initial design and was tested on simple driving cycles which exposed some problems. Some of these problems were solved by using alternative components or equipment. These alternative solutions were then specified for the final design solution. Some problems however, could only be solved using expensive equipment. This equipment was specified for the final solution although it was not used in the prototype. In addition, an alternate solution is specified which can be used if the user is not limited by a strict budget. It should be borne in mind throughout the report that the author restricted himself where possible to equipment that was available to him in the stores, thus keeping prices to a minimum.

The mechanical driver consists of an hydraulic circuit and is controlled by a BBC computer. The hydraulic circuit serves two pistons which operate on the brake and accelerator pedals. During a test, the computer monitors the vehicle speed and compares it to the theoretical driving cycle speed. If they differ by more than the accuracy limits specify, the computer sends a signal to the hydraulic pistons to take corrective action by moving either the accelerator or brake pedal. The vehicle speed sampling rate can be varied by changing certain parameters in the computer program. At the end of the cycle, the computer gives an error analysis which supplies information such as maximum deviation from driving cycle and standard error. A frame which provides support and rigidity to the hydraulic pistons fits onto the driver's seat-rail. The rest of the equipment fits onto a portable trolley which can be positioned next to the vehicle during a test (because the vehicle is stationary on rollers) and stored easily when not in use.

During the prototype tests the "driver" caused the vehicle's speed to "hunt" around the desired cycle speed. This was particularly apparent at points on the driving cycle where a sudden acceleration or deceleration was required and could not be anticipated by the computer.

By changing the sampling rate and the accelerator movement per speed difference the "driver" was able to reduce, but not eliminate, the hunting to conduct a simple driving cycle. The accuracy was improved by changing the computer program to "look ahead" in the driving cycle in an attempt to anticipate sudden drastic accelerations or decelerations. An emergency stop button was also allocated to a key so that the "driver" can be disengaged at any stage.

The report is concluded with a recommendation that a project be proposed where the mechanical driver is adapted to enable it to change gears when fitted to a vehicle with a manual transmission.

ACKNOWLEDGEMENTS

I wish to express my appreciation for the helpful advice and encouragement received from the supervisor of this project, Mr A. Yates.

I am also indebted to Mrs M. Lawler who spent many patient hours typing this report.

I also wish to extend my gratitude to the CSIR for their financial support without which this project would not have been possible.

University of Cape Town

CONTENTS

	<u>PAGE</u>
ABSTRACT	(11)
ACKNOWLEDGEMENTS	(v)
CONTENTS	(vi)
LIST OF ILLUSTRATIONS	(1x)
GLOSSARY	(x)
1. INTRODUCTION	1
2. LITERATURE SURVEY	5
3. DEFINITION OF PROBLEM	9
3.1 Problem Statement	9
3.2 Requirements	9
3.3 Constraints	9
3.4 Criteria	10
4. SOLUTION SPECIFICATION	11
5. CONCEPT FORMATION	14
5.1 Working Medium	14
5.1.1 Pneumatic	14
5.1.2 Hydraulic	15
5.1.3 Electrical	15
5.2 Servo Mechanism	15
5.2.1 Hydraulic/Pneumatic piston	16
5.2.2 Stepping motor	16

CONTENTS

	<u>PAGE</u>
5.3 Solenoid Valves	17
5.4 Motor and Pump set	20
5.4.1 Motor	20
5.4.2 Pump	21
5.5 Feedback	22
5.5.1 Vehicle speed feedback	22
5.5.2 Pedal position feedback	23
5.6 Power Supply	24
5.7 Mechanical Driver Frame	25
5.7.1 Frame across both the front seats	25
5.7.2 Frame in place of the driver's seat	26
6. DISCUSSION OF SOLUTION	28
6.1 Hydraulic Circuit	28
6.2 Pistons	30
6.3 Solenoid Valves and Switchgear	30
6.4 Pump and Motor set	33
6.5 Feedback	34
6.6 Power Supply	34
6.7 Computer Control	35
6.8 Computer Program Flow Diagram	37
6.9 Mechanical Driver Frame	40
6.10 Operating the Mechanical Driver	40
6.11 Procedure for setting up the Mechanical Driver	41
6.12 Time Analysis	43
6.13 Alternate "no cost limit" solution	44

CONTENTS

	<u>PAGE</u>
7. RESULTS	47
8. CONCLUSIONS	49
9. RECOMMENDATIONS	50
10. REFERENCES	51
11. APPENDIXES	A-1
Appendix A - Description of Prototype Mechanical Driver	A-1
Appendix B - BBC Computer Program Controlling the Prototype Mechanical driver	B-1
Appendix C - Description of the ECE Driving Cycle	C-1
Appendix D - Cost Analyses	D-1
Appendix E - Main Drawings	E-1

ILLUSTRATIONS

<u>FIGURE</u>		<u>PAGE</u>
Figure 1	Typical driving cycle showing periods of acceleration, deceleration, idling, constant velocity etc.	2
Figure 2	The closed loop system	18
Figure 3	Closed loop proportional valve using internal feedback	19
Figure 4	Side view of frame across both the front seats	25
Figure 5	Top view of frame mounted on the driver's seat rail	27
Figure 6	Hydraulic circuit layout	29
Figure 7	Circuit diagram of switchgear	32
Figure 8	Process control diagram	37
Figure 9	BBC Computer program flowchart	39
Figure 10	Hydraulic circuit of alternate "no cost limit" solution	46
Figure 11	Diagram showing driving profile by the prototype	48
Figure 12	Photograph showing the prototype mechanical driver in position	A-2
Figure 13	Half of the ECE urban driving cycle as used by the SABS.	C-3

GLOSSARY

a.c.	- alternating current
armature	- the rotating part of a d.c. motor that produces torque
BBC	- British Broadcasting Corporation
Bundy tube	- steel tubing used to transport hydraulic fluid
commutator	- conductor used to conduct electricity to the armature of a d.c. motor
d.c.	- direct current
dynamometer	- instrument to measure vehicle engine power
ECE	- Economic Commission for Europe
ERI	- Energy Research Institute
feedback	- return signal used in the control of a process
field	- the part of a d.c. motor that produces the electric field
hunting	- the oscillation of a vehicle speed around a required speed
hydraulic	- process operated by movement of a liquid e.g. oil
pneumatic	- process operated by movement of compressed air
positive displacement pump	- hydraulic pump with low volumetric losses
potentiometer	- instrument used for measuring an adjusting position
rpm	- revolutions per minute
SAE	- Society of Automotive Engineers
transformer	- instrument used to regulate the voltage of an alternating current

CHAPTER ONE

INTRODUCTION

The testing of road vehicles for fuel economy or exhaust emissions requires that they be operated under representative and accurately reproducible driving conditions. Driving patterns in a particular city or country are studied and a driving cycle similar to Figure 1 is produced which represents the driving style in that particular city or country. From Figure 1 it can be seen that a driving cycle is reproduced in the form of a graph with the vehicle speed plotted against time. A number of such representative driving cycles have been formulated for different countries. The one which has been selected by the South African Bureau of Standards for use in South Africa is the European Driving Cycle ⁽¹⁾ (ECE or Economic Commission for Europe cycle) which sets down total distance travelled, acceleration rates, constant velocity periods, times of idling, etc. (reproduced and described in Appendix C)

The testing of vehicles using driving cycles can be carried out over a level stretch of road. However problems such as varying traffic and weather conditions and difficulty in following verbal instructions required to adhere to the cycle make this method inaccurate and inconsistent. In order to overcome these problems, rolling road dynamometers have been utilized to simulate the moving road with the vehicle remaining stationary on the rollers. In this way the vehicle can be worked on while it is in "motion".

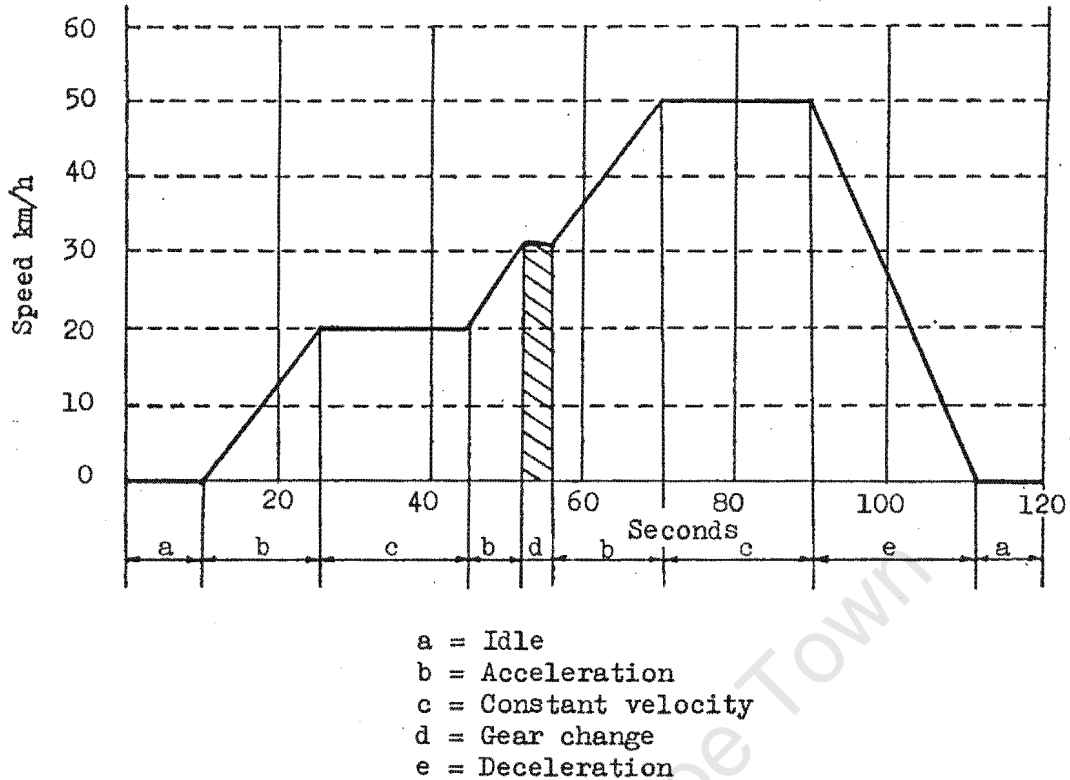


Figure 1 Typical driving cycle showing periods of acceleration, deceleration, idling, constant velocity etc.

The Energy Research Institute (ERI) at the University of Cape Town carries out many tests on a rolling road dynamometer. Its' design is such that it can be used for simulated journeys over any cycle or terrain since the effects of such parameters as inclines, wind speeds etc, can be programmed into a computer which controls the rolling road dynamometer.

The system can be used for tests to determine:

- the effect of fuel blends and fuel additives on fuel economy and emissions;

the effect of vehicle tuning on economy, emissions and performance;

comparison of various lubricant and lubricant additives on economy;

the effect of various driving cycles on economy and emissions; and

the effect of human drive error and drive styles on fuel economy.

Many of these tests involve using driving cycles such as the ECE cycle. These driving cycles tend to be long and repetitive. Consequently, the driver finds it boring and difficult to repeat a specified driving pattern within the given tolerance which is required when testing vehicles on a comparative basis. Even at the highest concentration, the test driver cannot obtain comparable results in the long run. Physical stress is often the main reason for failures which affect the test result or make it invalid. Especially in the case of endurance tests this can have far reaching consequences.

Even if the test is carried out with the admissible tolerances, the different driving mode causes strongly deviating measuring results. In addition, an uneven accelerator application can cause measurable variations in exhaust gas and consumption values.

One solution to this is the use of a mechanical driver, where the vehicle being tested is "driven" mechanically and controlled by a computer. The mechanical driver assumes the function of the test driver and provides measuring results which can be reproduced better and which have a maximum of measuring and control accuracy.

At present the E.R.I. employs a technician to drive the vehicle during tests. It has been found that due to the intense concentration required to get a vehicle to follow an ECE driving cycle, the maximum number of reasonably accurate cycles that can be driven in one day is approximately five. This figure can at least be doubled with the use of a mechanical driver.

The object of this thesis was to design a mechanical driver capable of "driving" an automatic vehicle over various driving cycles. The driver was designed for use in automatic vehicles with the intention of adapting it for use in manual vehicles at a later stage. However time prevented the second phase from materialising and this is recommended if work in this field is to continue.

In this report the author reviews previous work in this field and then defines the problem in detail mentioning the requirements, constraints and criteria of the design. This is followed by a description of the final design solution and a mention of all the other solutions that were considered. The author then discusses the design in detail giving advantages and disadvantages, assumptions, codes etc. The report is concluded with recommendations for further work in this field. A prototype mechanical driver that was built is described in an appendix.

CHAPTER TWO

LITERATURE SURVEY

Mechanical drivers have been used by many European car companies for exhaust emission control tests where cars have to undergo a fixed driving pattern to satisfy regulations. The pattern is repeated many times as tuning adjustments are made to the engine.

Volkswagen in West Germany built a mechanical driver for their motor vehicle exhaust emission programme in 1977. ⁽²⁾ This mechanical driver was designed for use in vehicles with an automatic transmission. It could be programmed to reproduce any driving cycle. The mechanised driver had a power supply which was independent of the vehicle's electrical system and was self-deactivating in situations where the actual speed differed from the theoretical speed by more than ± 15 km/h.

The entire system was governed by a speed control unit, which was computer controlled with a punch tape storage facility. It compared the theoretical and actual speed values and generated a signal to two servo motors which either moved the throttle or the brake pedal, keeping the vehicles' deviations from the prescribed speed pattern as low as possible. The control unit was adjusted by means of potentiometers so that the characteristic of the control unit could be varied according to the required speed deviation accuracy (difference between actual speed and theoretical speed). It could be set to keep speed deviations within the narrow limits ($\pm 0,5$ km/h) which caused rapid jerky movements of the accelerator pedal. On the other hand it could be set for larger speed difference tolerances which resulted in a much smoother throttle motion.

Volkswagen found that any quick movement of the throttle was undesirable because it produced unrealistic fuel consumption and emission figures. Thus when vehicles were tested on a comparative basis, the speed control unit was adjusted so that the motion of the throttle was as smooth as possible. However, the speed deviation between theoretical and actual was high (as much as 10 km/h in some driving cycles). A frame was installed in the place of the front passenger's seat, on which the measuring equipment, the speed control unit and a punched-tape reader were mounted one on top of another. Arranging the frame in this way provided a quick and easy method of installing and removing the measuring and control equipment.

Volkswagen concluded by saying that, for repetitive tests, the mechanised driver fully met the decisive requirement for its' use in the standard vehicle i.e. the high reproducibility in following a given driving cycle.

Ford Motor Company of America had an automatic driver system designed by their Product Development Group ⁽³⁾. The system "drove" the vehicle by applying the accelerator and brake pedals directly and, unlike the Volkswagen driver, also shifted the transmission if the vehicle was equipped with a standard transmission. It consisted of a electronic control console including a magnetic tape recorder and a servo hydraulic mechanical console. The mechanical console, which consisted of high response hydraulic rams, was linked to fixtures in the vehicle via flexible mechanical push-pull cables. These fixtures were attached to the accelerator, brake and clutch pedals as well as to the gearshift. The main advantage of this driver above all the other drivers mentioned here was that all the equipment was remote from the vehicle. This permitted the design of actuating fixtures which were compact, light weight and therefore easy to install and dismantle.

Test results indicated, based on several empirical parameters, that the system "drove" the vehicle more repeatably than even the best human driver.

Carl Schenck, a West German Company designed a mechanical driver for Austin Rover in Britain ⁽⁴⁾. It was portable and could be made to fit any vehicle. The "driver" was programmed by a single manual setting-up procedure. For this purpose the individual setting values which were different for each type of vehicle, were input in the dialogue mode via a keyboard. The speeds were selected manually and the gearshift positions (for a maximum of 9 speeds) were preset and stored automatically. The points of clutch engagement for the preset gearchanges were executed automatically during the cycle. All positions determined in this way were recorded and stored by the microprocessor system. The brake, clutch, accelerator and gearchange mechanisms were operated servopneumatically. An advantage of using pneumatics was it's clean and non-toxic operation. However it tended to be spongy which is undesirable when accurate piston positioning is required. A remote-control unit permitted one-man operation from the vehicle when setting up the "driver." The "driver" conducted the ECE driving cycle within the ± 1 km/h ⁽⁵⁾ speed tolerance band and the $\pm 0,5$ second time tolerance band.

Yet another mechanical driver was developed by Britain's independent Motor Industry Research Association ⁽⁶⁾. Available to auto manufacturers on a customer-contract basis, the electro-hydraulic rig had a box-like tubular frame that could be fitted in a car without the need to remove seats or make any modifications. Three hydraulic cylinders operated the clutch, brake and throttle pedals, while two more were paired to move the gear selector lever through any required gate for either manual or automatic transmissions.

The five servo actuators moved between preset reference positions indicated by displacement transducers. An advantage of using hydraulics was the fact that hydraulic oil is incompressible which provides a definite displacement without any sponginess. This is important when controlling pedal position.

During manual shifts the throttle was positioned according to an engine-speed feedback signal, reverting to a roll-speed signal after clutch engagement. An advantage of this system is that shift force applied to the gear lever was limited to a preselected level, and in case of a baulked synchomesh the actuator would return to neutral and try again. This prevented damage being caused to the gearbox and time being wasted on baulked transmission. A dedicated microcomputer controlled the drive cycles. A user-friendly teaching program for the actuators required only the manual positioning of each vehicle control, and stored the position data in the computer by depressing one key. Accuracy figures were unavailable for this system.

CHAPTER THREE

DEFINITION OF PROBLEM

3.1 Problem Statement

A design of a mechanical driver is required.

3.2 Requirements

3.2.1 The system must be able to drive an automatic vehicle over the ECE driving cycle within the specified accuracy limits as detailed in Appendix C.

3.2.2 The system must return repeatable results when testing vehicles for fuel consumption, emissions, speeds etc.

3.2.3 The system must be able to fit on the driver's seat rails of any vehicle and remain rigid.

3.3 Constraints

3.3.1 Where possible, components for the driver must be suitable for manufacture in the Mechanical Engineering Department's workshop.

3.3.2 Standard equipment must be used where possible.

3.3.3 The system must be designed for use in vehicles which are being tested on the rolling road only.

3.3.4 The system must have an emergency stop for critical situations.

3.4 Criteria

3.4.1 Production costs must be kept below R3 000.

3.4.2 Controls and equipment must be easy for a semi-skilled person to operate.

3.4.3 The system must be easy for a semi-skilled person to install and dismantle.

3.4.4 The system's control must be able to be varied so that different driving accuracies can be obtained.

CHAPTER FOUR

SOLUTION SPECIFICATION

Hydraulic Solenoid Valves

Bosch NG6 No 0 810 090 129 with subplate. 12V d.c. power supply. Switch-on time 20-60 ms. Switch-off time 10-60 ms. Maximum operating pressure 315 bar. Maximum flowrate 50 l/min. Mass 1.9 kg.

Hydraulic pistons

100 mm stroke. Two way action. Internal diameter 15 mm. External diameter 25 mm. Designed for manufacture in Mechanical Engineering Workshops.

Electric Motor and Pump

G.E.C. d.c. motor $\frac{1}{8}$ h.p. Speed variable 0 - 900 rpm. Motor drives Viking positive displacement pump via a flexible coupling. Pump capable of delivering hydraulic fluid at 67 cc/revolution at 20 bar at 900 rpm but operates at 7 cc/revolution at 6 bar at 700 rpm.

Hydraulic circuit

Piping made of 10 mm diameter Bundy tube. Connectors, tees and unions - standard equipment, supplied by manufacturer. Safety pressure valve designed for manufacture in the Mechanical Engineering Workshops. Tank supplied by the ERI.

Computer

B.B.C. microcomputer in conjunction with Acorn microcomputer. Already installed with rolling road dynamometer.

Solenoid Switchgear

Made up from standard electrical components which include transistors, diodes, resistors and capacitors.

Power Supply

Solenoid switchgear can be powered from a separate 12 V battery or from the vehicle's battery by plugging into the vehicle's cigarette lighter socket. Tests are conducted while the vehicle remains stationary on the rolling road dynamometer which is situated in a large laboratory, thus mains power is available. The d.c. motor is powered from the mains via a variac transformer which converts 220 V a.c. into a d.c. voltage that can be varied between 0 and approximately 200 V.

Mechanical Driver frame

Mild steel. Adjustable for different vehicles. Mounted on driver's seat rail.

Feedback

Vehicle speed feedback to the computer is from a pick-up on the rollers and is built into the dynamometer. Pedal position feedback to the computer is by means of a circular potentiometer which is connected to the ram of the piston. The computer reads the position of the ram as a value between 0 and 1,8 and converts it to a value between 0 and 65536.

Computer control

A computer program controls the driver by comparing the vehicle speed to the theoretical cycle speed and then sends a signal to the solenoid valves to either depress or release the accelerator or brake pedals to minimise the speed difference. An emergency stop button on the computer keyboard allows the operator to retract the cylinders at any time.

Cost to construct prototype

Without including labour and components that were available in the ERI stores, the prototype costs R2 700 to construct.

University of Cape Town

CHAPTER FIVE

CONCEPT FORMATION

In this chapter all the various solutions that were considered are described with the justification of the choice of the final solution.

5.1 Working Medium

Three working mediums were considered; pneumatic, hydraulic and electrical

5.1.1 Pneumatic - compressed air (pneumatics) can be used in a similar way as hydraulics. Similar valves and piping can be used with the hydraulic pump being replaced by a compressor. A disadvantage of pneumatics is that it is compressible. This was undesirable since the positioning of the piston was crucial and must not be susceptible to fluctuations in pedal or line pressure. Also, a relatively large container was required as an air reservoir which, together with a compressor, would make a portable device bulky. Advantages were that compressed air is clean and non-toxic and no return lines are necessary. It is easy to maintain and the circuit components are cheaper than their hydraulic equivalent.

5.1.2 Hydraulic - hydraulic oil is used in many applications where piston movement is required. It can be used at high pressures and is incompressible. Because of its many applications, maintenance and spares are readily available. A disadvantage of hydraulics is that fluids are susceptible to leaks and some oils can be corrosive.

5.1.3 Electrical - if stepping or servo motors are used to move the pedals then electricity in both a.c. and d.c. form can be used. Electricity is cheap but in most cases it is the price of the component it drives that offsets this option.

Hydraulic oil was chosen as the working medium in this design. The main motivation for this was the incompressibility of the fluid. Because accuracy was one of the requirements of the mechanical driver, it would be undesirable for either of the pedal's position to be varied once it had been moved to a specific position.

5.2 Servo Mechanism

The servo mechanism is the component that both depresses and releases the brake and accelerator pedals. It must include some form of feedback so that the pedal position can be determined at any moment.

- 5.2.1 Hydraulic/Pneumatic piston - the hydraulic and pneumatic piston is virtually the same except for the working fluid and is thus discussed under the same heading. A two-way acting piston would be required. These pistons were readily available in a variety of sizes and strokes with the pneumatic piston being slightly cheaper than the hydraulic piston. Pistons with low friction seals and spherical bearing male clevis were available from a local hydraulics company. These pistons have very little friction and hysteresis which improve accuracy and reduce hunting. These pistons however, are very expensive. Feedback to the computer on the position of the piston ram could be supplied by a potentiometer.
- 5.2.2 Stepping motor - a stepping motor is essentially a d.c. motor in which the output shaft can be made to move in a series of discrete angular steps. A special electronic drive circuit is required to apply the current pulses to a series of windings in a rotating sequence. A worm gear would be necessary to translate the shaft's circular motion into a linear motion to depress the pedals. The main disadvantage of stepping motors was that both the motor and the drive was very expensive. Maintenance is specialised and thus also costly. Some advantages of stepping motors are that they have no commutator, brushes or slip rings - reliability is therefore very high.

Precise speed control is possible to a high accuracy with no long term error. Accuracy and repeatability is extremely high. Feedback could be supplied by a built-in potentiometer.

It was decided to use "workshop manufactured" hydraulic pistons because stepping motors and low friction pistons, although accurate, are very expensive. The pistons would be cheap and easy to maintain.

5.3 Solenoid Valves

Solenoid valves are hydraulic valves that can be opened and closed electrically by means of solenoids. Many makes of solenoid valves were available on the market and the author decided on Bosch valves because these could be readily supplied and serviced by a local supplier. One solenoid was required for opening and one for closing the valve. The opening and closing of the valve can be performed in milliseconds.

On visiting a local hydraulic company⁽⁷⁾ it was established that there are various solutions to a closed-loop system which is required here. The system is said to be closed because feedback is used and compared to the desired reference value (setpoint). The error signal resulting from this setpoint/feedback comparison is processed into a correcting variable in the controller and is sent to the actuator so that errors are continuously corrected (Figure 2). The method of feedback can be internal or external and this gave rise to two possible solutions.

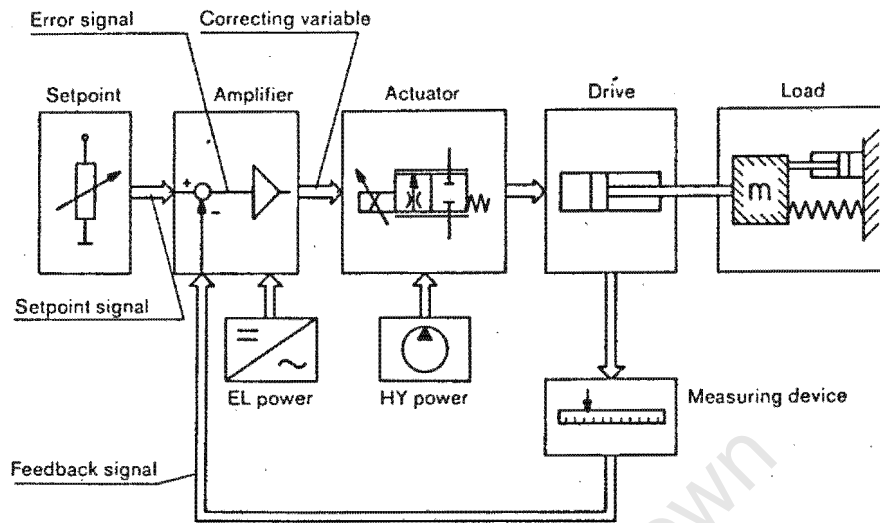


Figure 2 The closed loop system

Figure 3 shows a closed loop proportional valve which uses internal feedback. The setpoint/feedback signal comparison is performed in the electronic closed-loop amplifier. An error signal is amplified, provided with a given transfer response (P, I, D - response) and is fed to the closed-loop proportional valve as a correcting variable. These valves are standard off-the-shelf valves and must be purchased with a proportional control amplifier (which is separate). Although these valves are ideal for the design in terms of accuracy and response, the major disadvantage is it's exorbitant price. The servo valves alone are in the order of R3 000 each whereas all the electrics which include PID controller, linear transducer (feedback), relay cards, power supply, comparator card etc cost up to three times that of the valve.

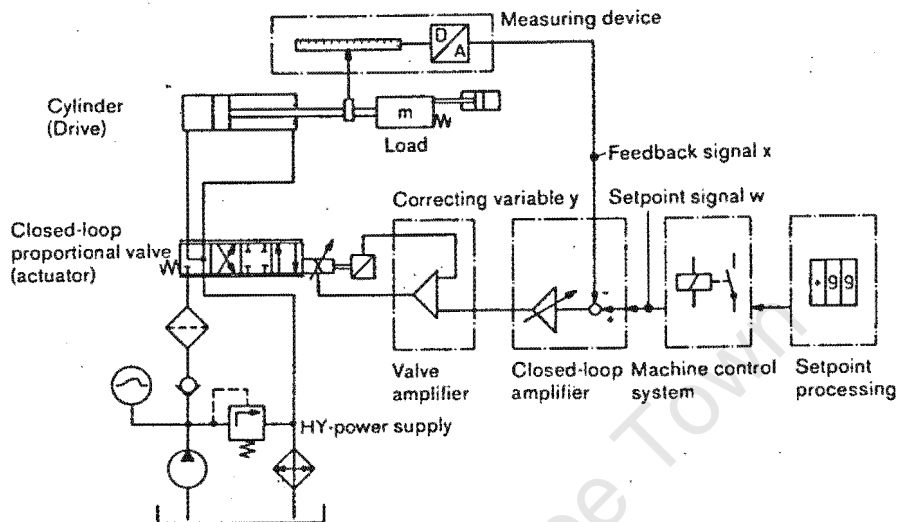


Figure 3 Closed loop proportional valve using internal feedback

External feedback, on the other hand, uses a potentiometer (or similar measuring device) to send a signal to an external component (e.g. computer) which compares the setpoint and feedback signals. The computer then sends a signal directly to a solenoid valve to take corrective action. Although conventional solenoid valves are not ideally suited to on-off switching applications, they are nevertheless a fraction of the price of the closed loop proportional valves (+- R600 each)

Since the production cost of the driver is an important criteria it was decided to specify the cheaper solenoid valve for the design.

The solenoid switchgear circuit is a common circuit used in many switching applications thus no alternate circuit was considered and standard electrical components were specified.

5.4 Motor and Pump set

Once hydraulics was chosen as the working fluid a suitable motor and pump set had to be selected to supply the solenoid valves with hydraulic oil at a suitable line pressure and flow rate.

5.4.1 Motor - a choice of an a.c. or a d.c. motor was available. A d.c. motor has the advantage that its' speed can be varied as the voltage applied to its' field and armature is varied. By using a d.c. voltage the motor speed could be set at the speed at which the optimum piston response was achieved. The a.c. motor on the other hand runs at a set speed, typically 960 or 1400 rpm. One disadvantage of a d.c. motor is that it is much more expensive than an a.c. motor. If the d.c. motor is to run off the mains, a variable transformer is required to convert the mains a.c. voltage into a variable d.c. voltage. In fact, two variac transformers are required, one for the armature voltage and one for the field voltage. Both a.c. and d.c. motors were available in the ERI store.

5.4.2 Pump - many types of hydraulic pumps were available from suppliers of hydraulic equipment, and it was a matter of choosing a suitable pump. The ERI on the other hand had a number of Viking positive displacement pumps which had been in use in a number of previous applications.

Thus an advantage of using Viking pumps would be that no new capital outlay would be necessary and because the ERI staff are familiar with these pumps, maintenance costs would be low.

Variable flow is normally achieved with a variable displacement pump and a fixed-speed a.c. motor because d.c. motors are much more expensive. However, it was decided to use a d.c. motor to drive a Viking pump via a flexible coupling. In the initial design solution, an a.c. motor was specified and used on the prototype. This proved unsatisfactory because the motor only ran at its' rated speed of 1440 rpm and did not allow for any speed variation to experiment with the response rate of the pistons and thus accuracy of the driver. Later a d.c. motor was fitted which could be run at various speeds. Optimum accuracy could be achieved after experimenting at different speeds. It was for this reason and the fact that a d.c. motor was available in the store that a d.c. motor was specified for the final design.

The Viking pump was chosen for the same reason and to keep costs low and keep components standard. The requirements of 7 cc/revolution at 6 bar and 700 rpm can be supplied by the Viking pump. A flexible coupling was specified so that any misalignment of the motor and pump shafts could be compensated for.

It should be noted here that a 2,2 kw a.c. motor together with a type S, size G gear pump would cost in the order of R500 each. This high cost is the main reason why "own equipment" which was "free" was specified by the author.

5.5 Feedback

Two forms of feedback were required; vehicle speed feedback and pedal position feedback.

5.5.1 Vehicle speed feedback - when the dynamometer was constructed a speed sensor was built into the rollers which could be fed into the computer. This method of speed feedback has always been used by the ERI, thus no alternate method was considered.

5.5.2 Pedal position feedback - information on the position of the accelerator pedal was an essential part of the control system as mentioned in 5.3. This information could be supplied cheaply and reliably by means of a potentiometer. Different types of potentiometers were available. The motion of the pedal can be considered to be linear (moves in a straight line) thus a linear rather than a logarithmic potentiometer was required.

Two types of potentiometers were considered - one that measured in a circular motion and one that measured in a linear motion. The circular potentiometer would have to be attached to a pulley so that the linear motion of the piston ram could be converted into a circular motion. The linear operating potentiometer on the other hand could be attached to the piston ram as is and measure piston movement directly. When these two options were investigated it was found that the maximum stroke available on a linearly operating potentiometer was only 80 mm. The stroke available on a circular potentiometer was limitless since the stroke depended on the size of the pulley. Also, a circular potentiometer was very cheap when compared to the price of a linear potentiometer.

Because the operating stroke of the hydraulic ram was 100 mm and because of the vast difference in costs, it was logical to opt for a circular potentiometer rather than a linear potentiometer for the pedal position feedback.

5.6 Power supply

The solenoids on the hydraulic valves were activated by 12 V d.c. This voltage could be supplied in one of two ways. Firstly, a portable 12 V battery could be used, although a disadvantage of this would be that it would have to be recharged regularly. Secondly, the 12 volts could be supplied from the test vehicle's battery. This could be done very easily by connecting the solenoid terminals into a cigarette lighter adapter and plugging this into the socket inside the vehicle. Advantages of this would be the ease of installation and the fact that the battery need not be charged.

The motor driving the hydraulic pump was a d.c. motor. It required two d.c. voltage sources - a constant 100 V d.c. source for the field and a variable d.c. source for the armature. A variable d.c. voltage source was not available in the testing laboratory but portable variable transformers, capable of converting a.c. mains into a variable d.c. voltage were available in the instrument store. Because of their suitability and availability, no alternate choices were considered. Two variable transformers were specified in the final design, one each for the field and armature.

5.7 Mechanical Driver Frame

Two different types of frames were considered; one that fitted across both the front seats and one that fitted in the place of the driver's seat.

5.7.1 Frame across both the front seats - this frame was made of 25 X 25 mm square mild steel tubing. As seen in Figure 4 the rectangular frame was supported at both ends with adjustable bars extending to the roof of the vehicle to give rigidity to the frame.

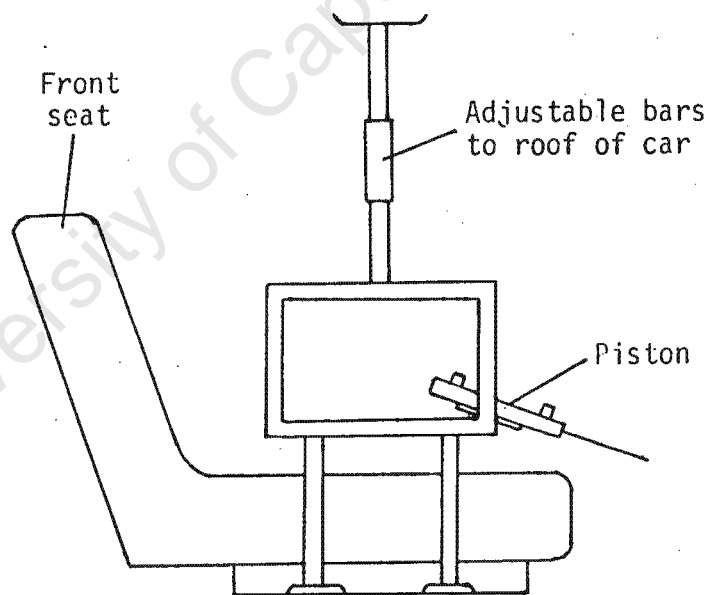


Figure 4 Side view of frame across both the front seats

An advantage of this frame was that neither of the front seats needed to be removed, but on the other hand, it was large and bulky which made it difficult to install. Also, because of the long distance between the frame and the pedals, pistons with a long stroke were required to move the pedals.

5.7.2 Frame in place of the driver's seat - this frame was also constructed of mild steel. It was designed to fit on the rail of the drivers seat. This provided rigidity and it could be adjusted backwards or forwards in the same way as the seat is adjusted. It could also be adjusted width-wise so that it could be installed into different vehicles. A disadvantage of this frame was that the driver's seat had to be removed for it to be installed. However, it was far less bulky than the frame across the seats which made it easier to set up. Also, shorter pistons could be used because the frame could be adjusted so that the pistons would be close to the pedals. Figure 5 shows a sketch of the frame from the top view.

It was decided to use the frame that fitted on the seat rail because it was less bulky, cheaper to construct and easier to install.

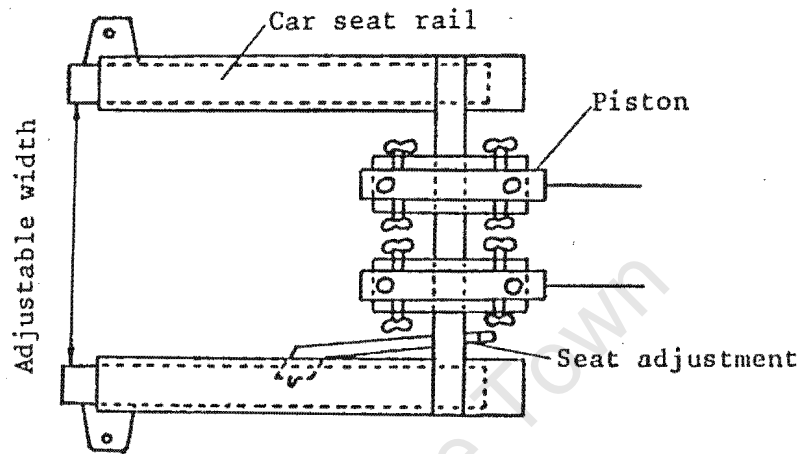


Figure 5 Top view of frame mounted on the driver's seat rail

CHAPTER SIX

DISCUSSION OF SOLUTION

The following is a discussion of the final design solution as seen by the author. It must be borne in mind that this was a low-budget design and that where possible, equipment already in the ERI's possession was specified. The design specified here is thus not an optimum one but one that is functional and inexpensive.

A prototype mechanical driver was built to an initial design solution and some faults were discovered. Most of these faults were solved by using alternate components or equipment. These solutions were then specified for the final design solution, which is discussed below.

6.1 Hydraulic Circuit

Figure 6 shows the hydraulic circuit layout. Standard 10 mm diameter Bundy tube is used for the circuit tubing. A d.c. motor is coupled to a constant flow hydraulic pump which pumps hydraulic fluid from a tank. When the solenoid valves are de-energised, i.e. closed, the oil flows from the pump, through the safety valve (1) and back to the tank. The safety valve is preset at a set pressure. If the system pressure falls below this set pressure, e.g. a solenoid valve opens, the safety valve will close and the oil will be directed up to the solenoid valve through the filter (2). Once the operation is complete and the solenoid valve closes, the system pressure is brought up to the safety valve preset pressure again.

At this point the safety valve opens and the oil is redirected back to the tank once again. In this way, the safety valve maintains the system pressure and prevents the build-up of pressure during operation.

The safety valve used on the prototype mechanical driver was designed for construction in the Mechanical Engineering workshops. A detailed working drawing of the valve is shown in Appendix E. The preset pressure is adjusted by screwing the bolt in or out to increase or decrease the pressure respectively.

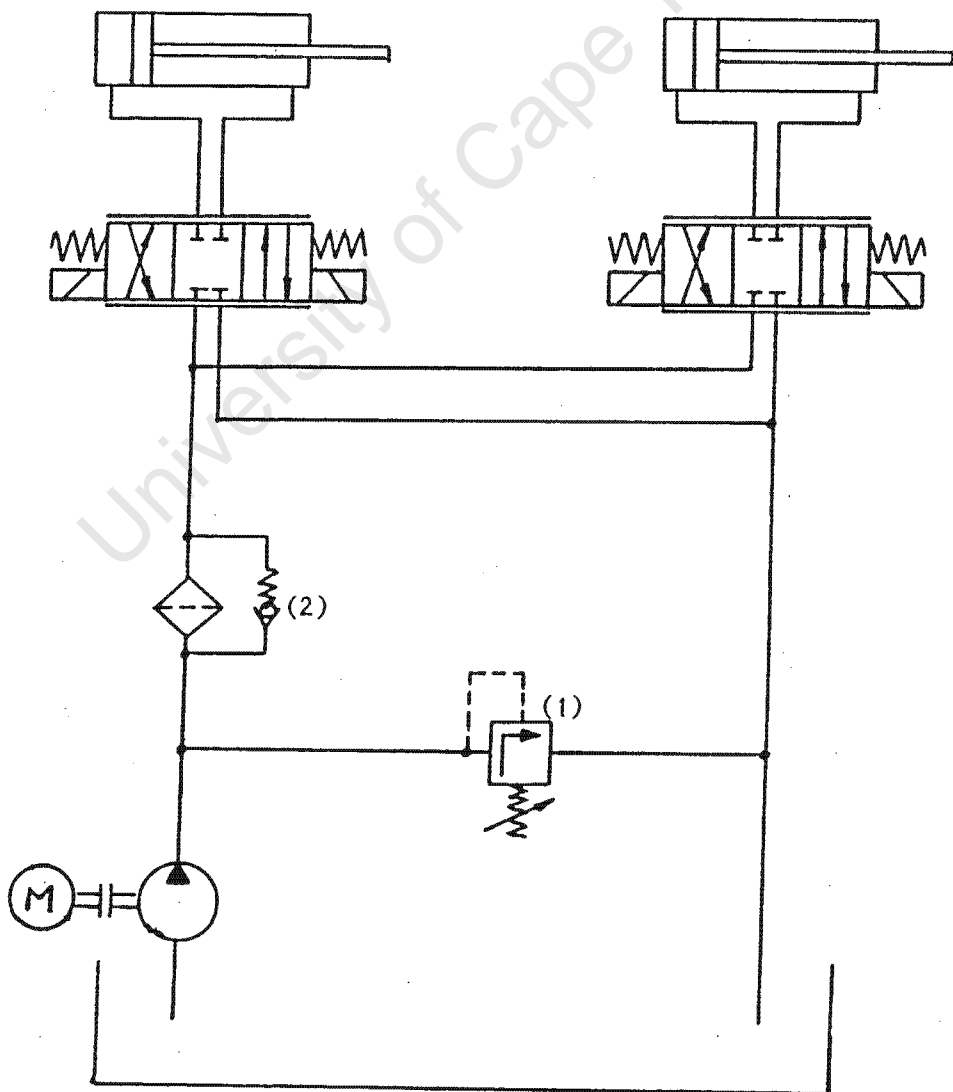


Figure 6 Hydraulic circuit layout

6.2 Pistons

The pistons are designed for construction in the Mechanical Engineering workshops. The pistons are made from 25 mm diameter low carbon steel bar with a reamed 15 mm internal diameter. The rear end of the piston is closed off with a threaded cap which can be removed for maintenance. The front end is similar except the cap has a 5 mm diameter hole drilled through the centre to accommodate the piston ram. It also has a spigot so that the piston ram hole is located centrally. Both ends are sealed with rubber gaskets. An inlet and an outlet port is silver soldered onto the piston and threaded so that the connectors from the hydraulic pipes can be attached. The ram is a stainless steel rod 5 mm diameter and 180 mm long with the piston on one end. The piston has a rubber oil seal fitted on the outside which prevents any oil leaking past it while in operation. Two circlips are fitted into the inner cylinder to set the extremities of the travel of the ram. In this design the circlips were set to give a stroke of 100 mm. The pistons are shown in detail in Appendix E.

6.3 Solenoid Valves and Switchgear

The two solenoid valves are Bosch NG6 directional control valves. Each valve has a maximum operating pressure of 315 bar and a maximum flowrate of 50 l/min which is well above design operating conditions. It was decided to use the NG6 valves above the smaller NG4 valves because the latter valves are no longer standard and are not available as off-shelf stock.

Each valve has two solenoids which are activated by a 12 V d.c voltage. When the one solenoid is activated the piston will extend and it will retract when the other solenoid is activated. If either solenoid is de-activated the valve will return to it's neutral position by means of a return spring.

The 12 V d.c. used to activate the solenoids can be supplied by a seperate battery or can be supplied by the battery of the car being tested by connecting the solenoid switchgear terminals into the cigarette lighter socket. Figure 7 shows the circuit diagram of the switchgear. Terminal A is connected to the output port of the BBC computer which is either high (5V) or low (0V). If terminal A is high, then transistor BC109 is switched on which in turn switches on transistor MJE3055. The 12 V rail has now been connected to ground so current will flow through the solenoid. If terminal A goes low (0V), the BC 109 is switched off which switches the MJE 3055 off. There is now an open circuit between the 12 V rail and ground so the solenoid is de-activated.

The diode which is placed in parallel with the solenoid prevents any back surge of current through the solenoid when it is de-activated. The MJE 3055 is a heavy duty transistor for applications with high currents.

The BC 109 can only take a few milliamps, therefore this transistor is used to switch on the MJE 3055 which will be able to take the current that flows through the solenoid. This switchgear circuit is commonly used in applications where high current switching is required.

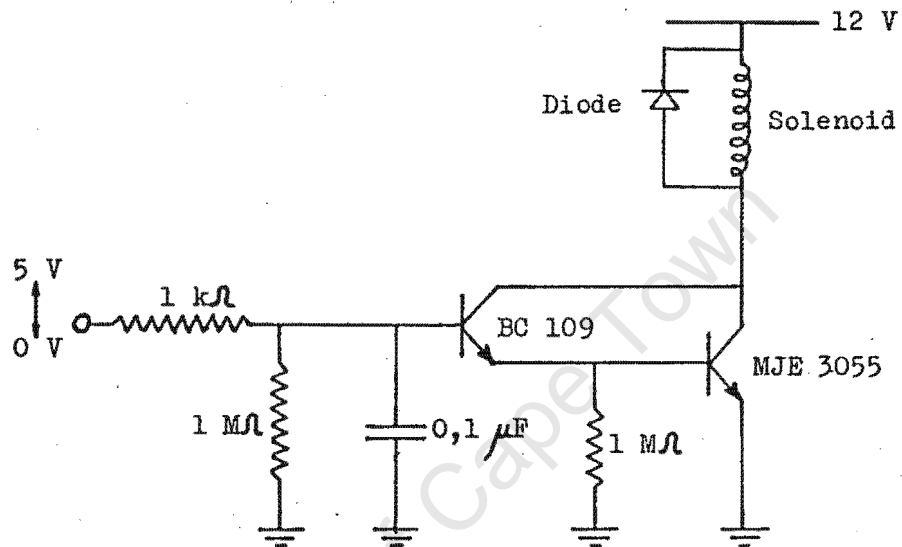


Figure 7 Circuit diagram of switchgear

6.4 Pump and Motor set

The motor is a GEC d.c. motor with a $\frac{1}{8}$ h.p rating. Because it is a d.c. motor, it is possible to run it at any speed between 0 - 900 rpm. The armature and field can be excited by separate variable currents. The power is drawn from the mains and passed through a variable transformer and enters the motor as a direct current which can be varied between 0 and approximately 200 volts. The field voltage must remain at a fixed 100 volts and the armature voltage can be varied according to whatever speed is required. It should be noted here that a d.c. motor would not have been specified for the design had it not been made available by the University. If building this design from scratch it would be far cheaper to use an a.c. motor coupled to a variable pump. D.C. motors are in the order of five times the price of a.c. motors and are only used in special applications.

The motor drives a positive displacement Viking pump via a flexible coupling. The coupling allows for slight misalignments between the motor and the pump shafts and absorbs any shock loads. The Viking pump is capable of pumping hydraulic fluid at 67 cc/revolution at 20 bar at 900 rpm, but for the purpose of the design, a flowrate of 7 cc/revolution at 6 bar at 700 rpm was set. The motor speed can be varied until these conditions are obtained. It was found that at high pressures and flowrates it was very difficult to move the piston short distances. The pistons have a small diameter and a short stroke, thus only a small flow is required to move them.

6.5 Feedback

As described in the previous chapter, the vehicle speed feedback was built into the dynamometer when it was constructed and is thus not a part of the design. The pedal position feedback on the other hand is a part of the mechanical driver design. The feedback is supplied by a circular potentiometer with an angular range of 270° . The potentiometer is attached to a pulley so that the linear motion of the pedal is converted into a circular motion, which can then be measured by the potentiometer. The size of the pulley is calculated so that the 100 mm piston stroke corresponds to the full 270° angular range of the potentiometer. String is wrapped around the pulley and attached to the piston ram so that as the ram extends, the pulley rotates thus changing the resistance of the potentiometer. The pulley is spring-loaded so that the string is kept taut in all pedal positions.

6.6 Power Supply

Power for the solenoid switchgear is supplied by the test vehicle's battery. The switchgear terminals are connected to a cigarette lighter plug so that the power can be supplied directly by inserting the plug into the cigarette light socket. This provides for a quick and easy installation.

The d.c. motor driving the hydraulic pump is powered by two d.c. voltage sources which are supplied by converting the 230 V a.c. mains into d.c. by means of transformers. The output of these transformers can be varied so that any d.c. voltage between 0 and 200 V can be supplied. The field is energised by a constant 100 V d.c. while the armature is supplied a voltage according to the motor speed that is required. By varying the armature voltage, the motor speed can be varied between 0 and 900 r.p.m.

6.7 Computer Control

At present the ERI uses two computers in conjunction with the rolling road dynamometer. One is an Acorn computer which is used to control the dynamometer. Parameters, characteristic of the particular vehicle being tested, are entered into the computer before the test. This computer controls the resisting torque which simulates the vehicle's inertia when the vehicle is under acceleration and deceleration and also simulates the wind drag resistance on the vehicle.

The other computer is a BBC computer coupled to a disc drive. A BBC computer is used here because it has been in use with the rolling road since the rolling road was built. It has a built-in analogue-to-digital converter which can read inputs at a rate of 20 msec (i.e. 50 readings per second). This computer is connected to two visual display units - one in the control room with the computer and one next to the car being tested. Vehicle speed feedback from the rollers is fed into the computer which is used to indicate the vehicle's speed and position on the driving cycle and is displayed on the screens.

At present the driver of the vehicle uses this visual display to anticipate the driving cycle in advance. Once the mechanical driver is in operation it will serve as an indication to the operator as to how accurately the driving cycle is being followed.

Figure 8 is the process control diagram which incorporates two feedback loops. The one is the vehicle speed feedback from the rolling road (f) and the other is from the piston position (e).

Starting at the left hand side of the diagram - the set speed (Y_{sp}) (from the ECE cycle) is compared with the actual speed (Y_a) which is fed back from the rolling road. This is read by the computer (a) which sends out a deviation signal (ϵ_1) to move the piston.

This signal is compared to the present piston position (Y_p) and the computer determines the new position. This results in the signal (ϵ_2) being sent to the solenoid valve (b) with the new piston position. All the above takes place in the computer which is the controller of the process. The process is described below.

The solenoid valve receives the signal and moves the piston (c) accordingly. This results in a vehicle speed increase or decrease (according to the speed error) since the piston acts on the accelerator pedal (d). The new piston position (e) and vehicle speed (f) is fed back to the computer to close the loop.

The above system is called a double feedback loop system⁽⁸⁾.

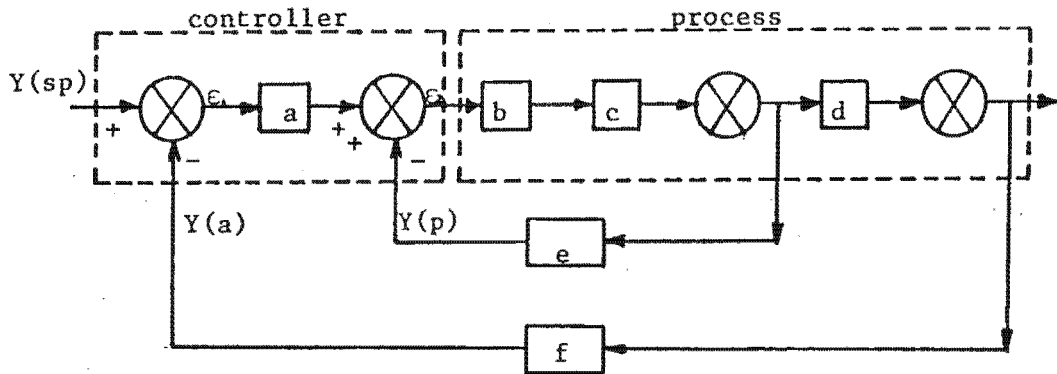


Figure 8 Process control diagram

6.8 Computer Program Flow Diagram

The flow diagram of the computer program is shown in Figure 9 and the program itself is reproduced in Appendix B. The following is a description of the flow diagram.

To start with, all the initial parameters are set. This includes setting the input and output ports to receive and relay information respectively. If a driving cycle different to the one last run (and thus still on disc) is to be used, then this new cycle is entered in intervals of one second and stored on disc. If the cycle to be driven is the same as the one used previously, it is called up from disc and stored in the computer memory. The cycle to be used is now stored in memory and ready to run. When the operator is ready, he presses the spacebar key which sets the timer and starts the cycle. The computer reads the actual speed from the dynamometer, compares it with the theoretical cycle speed and computes the error. This error is stored in a memory and used at a later stage to determine the cycle analysis (standard error and maximum error).

If the error is larger than the error calculated on the previous loop (i.e. the vehicle is deviating further from the cycle), the procedure for moving the accelerator pedal is executed. If the error is smaller than the previous error (i.e. the vehicle is being driven closer to the cycle), the program is paused for approximately half a second (to allow for a change in actual speed i.e. vehicle inertia) and a new loop is started if the driving cycle has not been completed.

If at any stage the cycle speed is zero i.e. the vehicle is idling, the procedure to press the brake pedal is executed. This is essential because all vehicles using this mechanical driver will have an automatic transmission (see Requirements 3.2.1) and automatic vehicles tend to crawl forward on idle.

In the accelerator pedal procedure, the pedal is depressed or released an amount proportional to the difference between the theoretical and actual speeds e.g. if the pedal is at position 20 (0 being the released position and 100 being the floored position) and the actual speed is 5 km/h below the theoretical speed, the accelerator will be pressed to position 25. After a pause the speeds are compared again and the necessary adjustments made. It is possible to change the amount by which the accelerator pedal is moved for each km/h the speeds are out, thereby varying the accuracy of the driver.

When the cycle has been completed the computer gives an error analysis which is an indication to the operator as to how accurate the cycle was executed. A standard error and a maximum error is given.

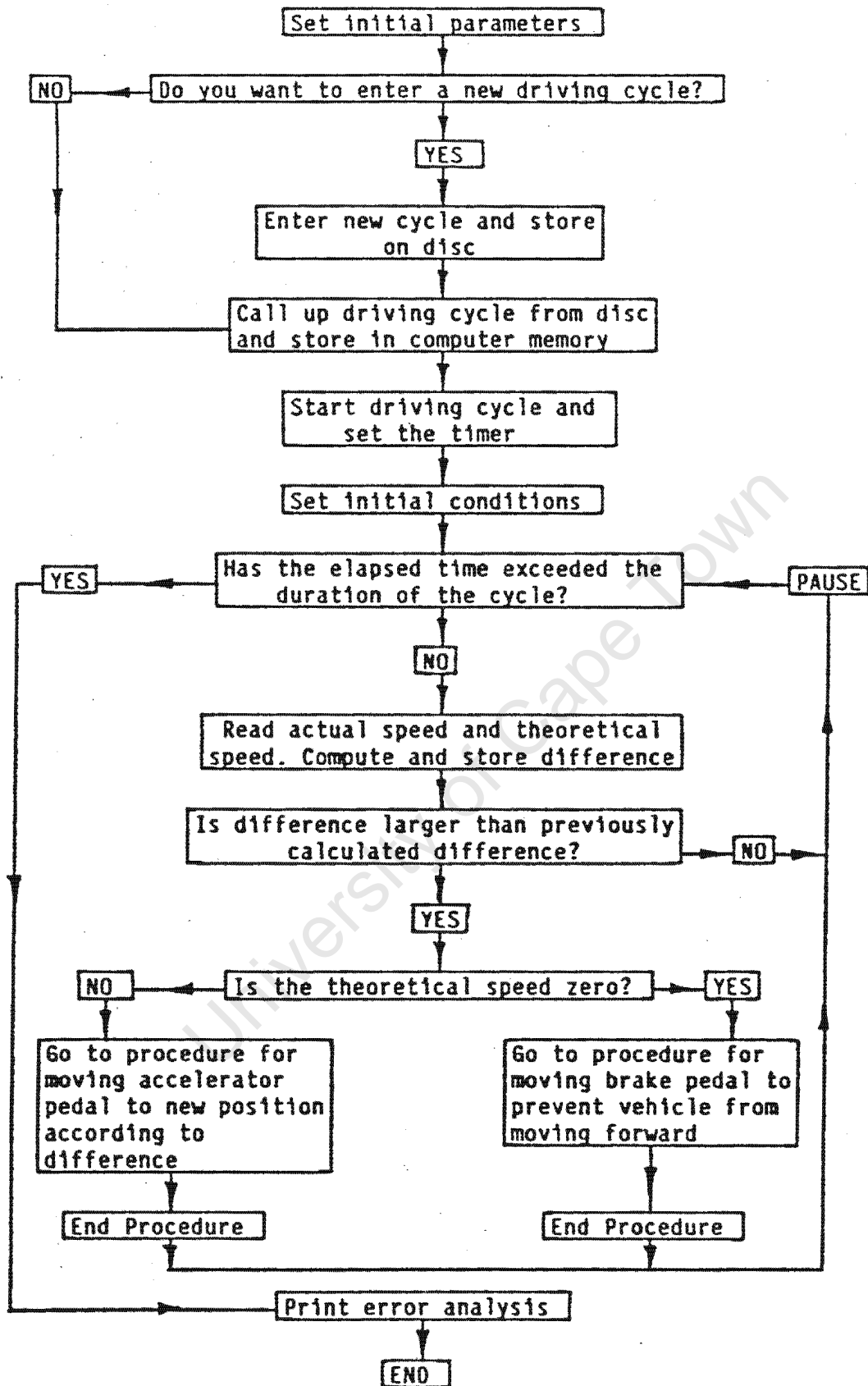


Figure 9 BBC Computer program flowchart

6.9 Mechanical Driver Frame

The frame is constructed from mild steel. It is designed to fit on the rail of the drivers seat. It can be adjusted width-wise so that it can be installed into vehicles with different seat rail widths. The frame can be moved backwards and forwards in the same way as the front seats of the car are adjusted.

The two hydraulic cylinders are secured onto plates which can rotate so that the cylinders can act on the pedals at various angles. The plates rotate on a horizontal bar which is supported by the frame (see the main drawings in Appendix E). The frame should take approximately ten minutes to set up.

6.10 Operating the Mechanical Driver

The prototype driver was tested over several simple driving cycles. Initially the mechanical driver caused the vehicle's speed to "hunt" excessively around the desired cycle speed. This was caused by the continual rapid depressing and releasing of the accelerator pedal which is considered undesirable⁽²⁾. The computer program was continually varied by changing the sampling rate and the distance of accelerator movement per km/h difference to improve on the driver accuracy. Time did not allow the prototype to be used on the full ECE cycle as the author was not satisfied with accuracy obtained on partial ECE cycle tests. The prototype was particularly inaccurate at points on the driving cycle where a sudden acceleration or deceleration was required. (See figure 11).

The computer could not anticipate a sudden change in speed and thus overshoot and took time to re-correct itself. The program was changed to read the cycle speed one second ahead of real time. This improved the accuracy at these points but still could not keep the driver within the allowed envelope.

An emergency stop button was also allocated to a computer key. Should the operator wish to terminate the test or should a dangerous situation develop for any reason, this emergency stop button can be pushed and both the hydraulic pistons would retract thus deactivating the driver.

6.11 Procedure for setting up the Mechanical Driver

Before any vehicle can be tested, the dynamometer inertia weights have to be selected according to the mass of the vehicle being tested. These inertia weights are attached to the shafts of the rollers and simulate the mass of the vehicle when it is under acceleration and deceleration. Also, because the vehicle remains stationary during tests, a cooling fan has to be placed in front of the vehicle to blow cool air through the radiator.

An extraction fan is also required to be placed over the exhaust pipe to prevent the exhaust fumes from polluting the laboratory. The following procedure should be followed when setting the mechanical driver up for a vehicle test.

1. Remove drivers' seat so that the rails are exposed.
2. Attach frame onto rail so that it can slide freely.
3. Position the frame so that the rams of the hydraulic pistons are firmly against the brake and accelerator pedals.
4. Lock the frame in position.
5. Connect ribbon cable into the computers' user port including wires to the switchgear and feedback from potentiometer.
6. Connect variable transformers to mains.
7. Connect switchgear to 12V source (either separate car battery or directly into cigarette lighter socket).
8. Enter the driving cycle into the BBC computer.
9. Once the computer is ready to run, energise the variable transformers and run the motor up to desired speed.
10. Switch on cooling and extraction fans.
11. Start the driving cycle from the computer. Note: Operator must remain at the computer so that he can push the emergency stop button if a critical situation develops.

12. Once the cycle is complete, note cycle error analysis.
13. Repeat steps 10 and 11 if cycle is to be re-run.
14. Once all tests have been completed, dismantle the equipment in reverse sequence as above.

6.12 Time Analysis

In this section, an analysis of all the time increments involved in the control process is made in an attempt to determine whether the driver is capable of "driving" the vehicle within the tolerance of the ECE cycle.

At the sharpest change in the driving cycle, corrective action can only be delayed by 0,5 seconds⁽⁵⁾. The time taken in the mechanical control i.e. from the voltage first appearing on the valve solenoid until the vehicle has reached the desired speed can be split up as follows:

Switching time on solenoid = 0,05 seconds
Piston movement to new position = 0,25 seconds
Assume vehicle inertia delay = 1,0 seconds

Thus it takes 1,30 seconds for the vehicle to reach the new speed.

Software delay can be presented as follows:

Computer reading of two speeds = 0,05 seconds
Computing and logging of error = 0,10 seconds
Sending of signal to solenoid = 0,05 seconds

Therefore a total of at least 1,50 seconds is required from the time the computer reads the speeds until the vehicle achieves it's new speed.

In an attempt to overcome this sluggish control behaviour, the computer program was made to "look ahead" by one second. This, in theory gave a delay time of 0,5 seconds which is within the ECE cycle accuracy envelope. In practice, however, delay time exceeded one second on some parts of the cycle (see Figure 11). The prototype mechanical driver was not tested with the "look ahead" algorithm of greater than one second.

A faster, more modern computer (e.g. IBM-compatible) would most certainly cut down on the BBC's software delay. In addition, closed loop proportion valves would reduce the control loop logic delay significantly. These systems, however, are expensive and the author did not have the funds available to purchase them to verify the above statement.

6.13 Alternative "No Cost Limit" Solution

Throughout the previous discussion, mention has been made of equipment that had been made available to the author by the University. This was done to keep costs as low as possible. However, should the accuracy of the driver be of a higher priority than the total cost, a different solution can be presented.

In 5.3 mention was made of closed loop proportional valves. These valves have their own feedback system (Figure 3) which is fed directly into the closed loop amplifier. This amplifier measures the error from the reference value of the desired vehicle speed. This error is then sent directly to the valve controller card which causes whatever pedal movement is necessary to reduce the error. Associated with these valves is a lot of "high-tech" electronics which come in the form of cards. These cards (relay card, amplifying cards, comparator card etc) can be mounted together in a rack for ease of operation and neatness.

Apart from the valve and electronics, other hydraulic equipment could be used to make the driver more efficient. (See Figure 10). These include an a.c. motor coupled to a gear pump, an accumulator charging valve (1), accumulator (2), pressure gauge (3), needle valve (bleed off valve) (4) as well as temperature⁽⁵⁾ and volume (6) switches, a level indicator (7) and filler/breather (8) on the tank. In addition, the servo-piston may be floating (with no seals) in order to minimise the friction and hysteresis which inevitably produce hunting.

The accumulator charging valve ensures a set pressure in the circuit and the accumulator prevents the valves from being starved of hydraulic oil in the event of a surge. The temperature and volume switches as well as the level indicator are safety features which prevent oil overheating and oil drainage.

An IBM-compatible computer together with an analogue to digital converter would process the data at a much quicker rate than a BBC computer can.

The above system would cost in the order of R28 100 (see Appendix D) and the circuit diagram is given below.

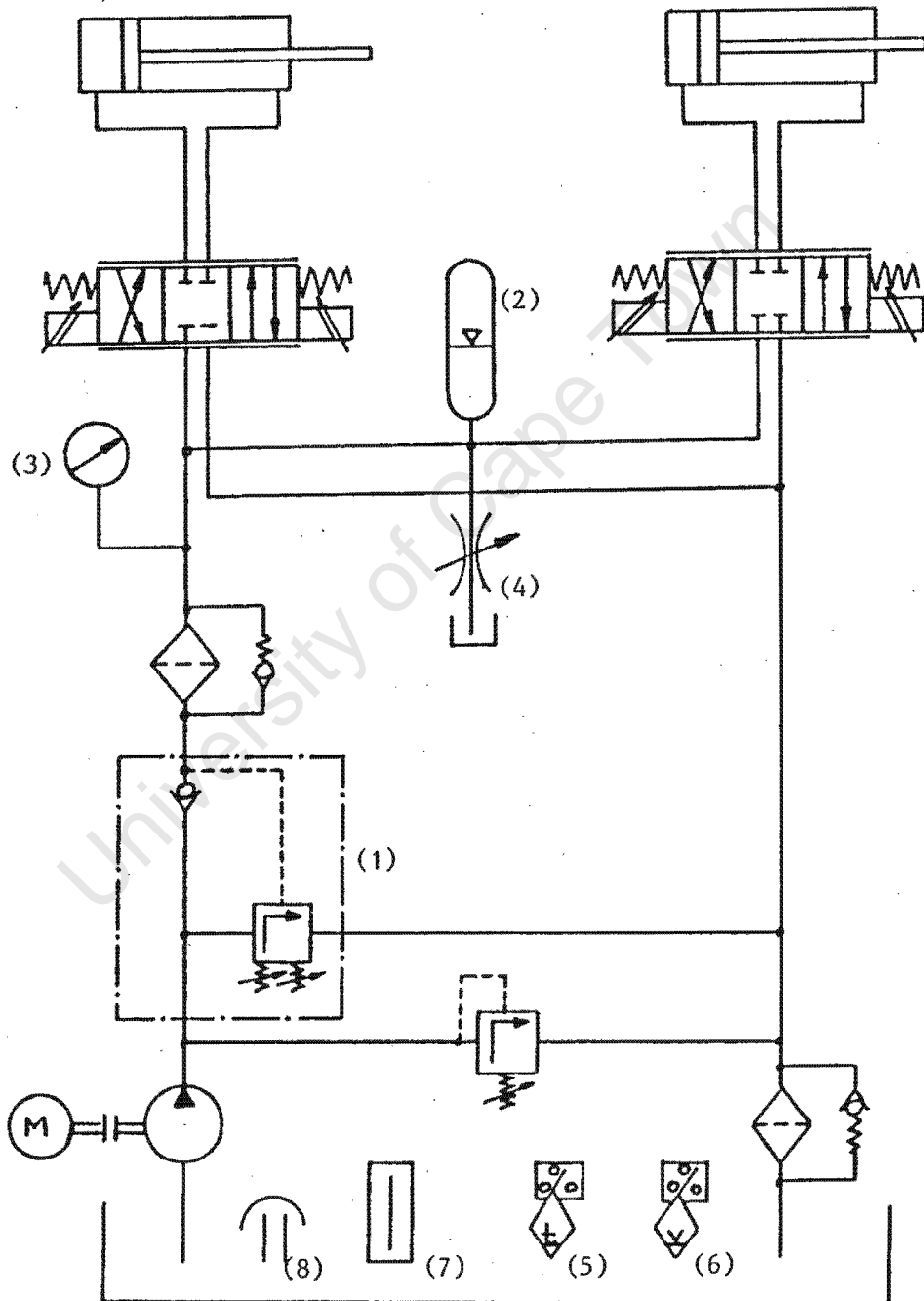


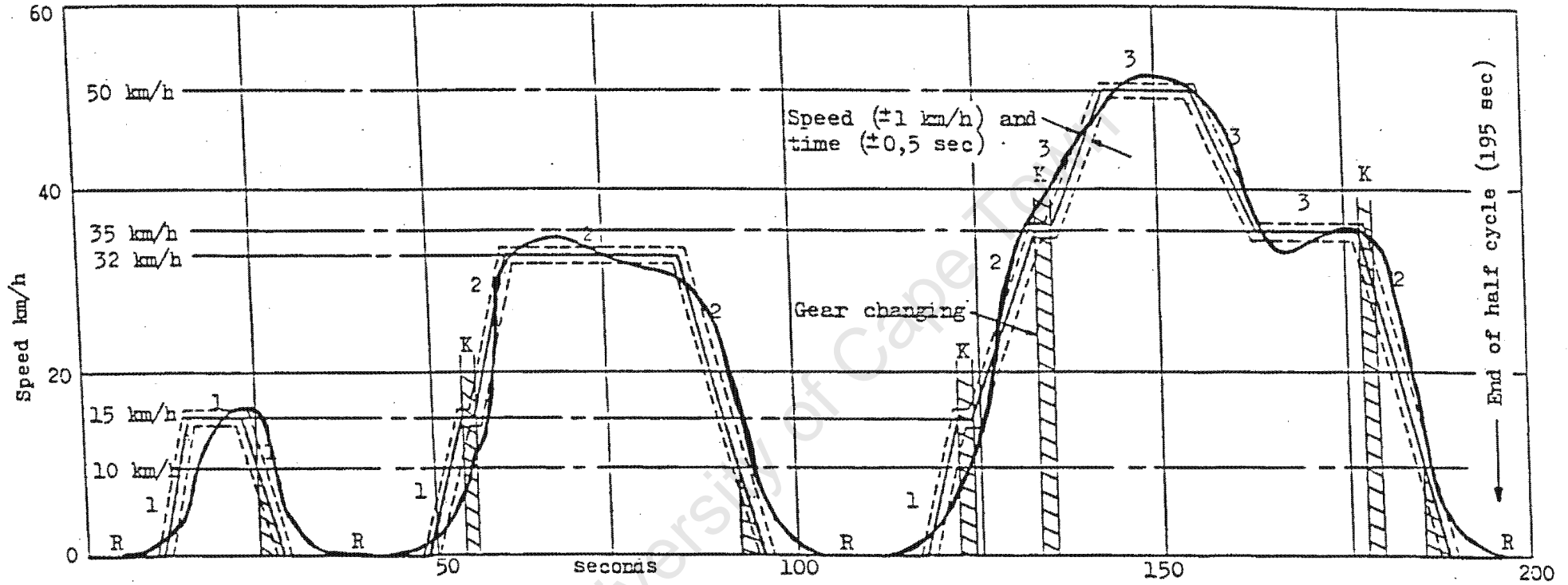
Figure 10 Hydraulic circuit of alternate "no cost limit" solution

CHAPTER SEVEN

RESULTS

Figure 11 shows the driving profile achieved by the prototype on the ECE cycle. It shows how the "driver" is particularly inaccurate at points where sudden acceleration or deceleration is required. It also shows how the "driver" hunts as it attempts to follow the cycle. These results were achieved with a one second "look ahead" algorithm.

It can be seen that the "driver" does not drive the vehicle within the ECE accuracy limits. These limits are particularly tight to achieve even with a human driver.



1=1st gear 2=2nd gear 3=3rd gear K=Declutching R=Idling

Figure 11 Diagram showing driving profile by the prototype

CHAPTER EIGHT

CONCLUSIONS

In the previous chapters it has been described how the final design solution was developed. Due to the limit on the available finance and the limitation on the use of equipment that was available to the ERI, this design is by no means optimal. Hunting for example, is inevitable with an on-off valve and the hysteresis of a normal piston seal has to be accepted without the use of expensive floating servo-pistons (with no seals). Also, with the use of more expensive closed loop proportional valves and its associated electrics, together with an IBM-compatible computer, a far greater degree of accuracy could have been achieved.

However, the prototype mechanical driver proved that with the limited equipment available, it was functional although it was unable to achieve the accuracy as specified in the ECE cycle.

CHAPTER NINE

RECOMMENDATIONS

The following are some problems encountered with the prototype mechanical driver and the design in general with recommendations the author wishes to make to anyone wanting to continue the project.

1. It was found that some alternate components had to be specified merely to keep costs low. The driver is to be built in the Mechanical Engineering workshops, thus any component that was readily available in the store and could perform a similar function to the required component was specified so that capital costs were kept as low as possible. Many of these components were old and out of date. It is recommended therefore, that where possible, the more expensive equipment mentioned as alternatives be used.
2. It is recommended that a project be proposed where the mechanical driver is adapted to enable it to change gears when fitted to a vehicle with a manual transmission.

CHAPTER TEN

REFERENCES

1. Dutkiewicz, R.K. and Nates, R. "Design and Construction of a rolling-road dynamometer for road vehicles", South African Mechanical Engineer, Volume 35, March 1985, pages 76 - 79.
2. Volkswagenwerk A.G., "Analysis of the measuring and testing procedures for motor vehicle exhaust emissions", Internations Off-Highway powerplant and Exposition Congress, Milwaukee, Wisconsin, September 10-13, 1983, pages 102 - 111.
3. Gryce, R.T. "Ford Auto/Emission Driver System", SAE transaction no. 741007, 1974.
4. Schenck, C., "Autopilot for program controlled driving of passenger cars on endurance and exhaust gas test stands", Phillips Industrial Automation 83/84, Darmstadt, West Germany.
5. "ECE" Method of measuring the fuel consumption of motor vehicles, Document TRANS/SCI/WP29/R.204 Annex 9, Page 5, no. 6.3.1.5.
6. Scott, D., "Robot driver controls car test cycle", Automotive Engineering, March, 1986, Volume 94, no. 3. pages 66-67.

7. Gill, R. Design Engineer, Hyflo Transvaal (Pty) Ltd, Wendywood, Sandton.
8. Stephanopoulos, G., "Chemical Process Control: An Introduction to Theory and Practice", Prentice-Hall, Inc., Engelwood Cliffs, New Jersey, 1984, pages 241 - 279.

University of Cape Town

CHAPTER ELEVEN

APPENDIXESAPPENDIX A - DESCRIPTION OF THE PROTOTYPE MECHANICAL DRIVER

The prototype mechanical driver was the same as the final design solution as described in previous chapters except that the frame was constructed differently. The frame was constructed in the Mechanical Engineering workshops and consisted of a mild steel plate bent to fit over the driver's seat. As in the final design solution, rails which were adjustable in reach supported a horizontal bar. This bar had two adjustable plates on which the two hydraulic cylinders were secured. The plates could rotate on the horizontal bar thus allowing the cylinders to act on the pedals at various angles. For rigidity of the structure a heavy object (in this case a car battery) was placed on top of the plate over the seat. This was not part of the design but proved successful. The frame was changed for the final design because the one used for the prototype was crude and not aesthetically pleasing.

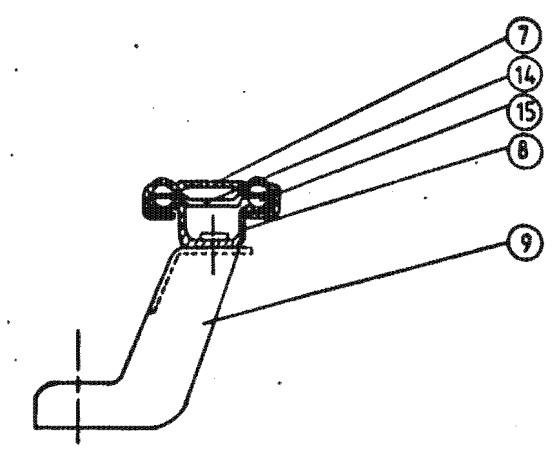
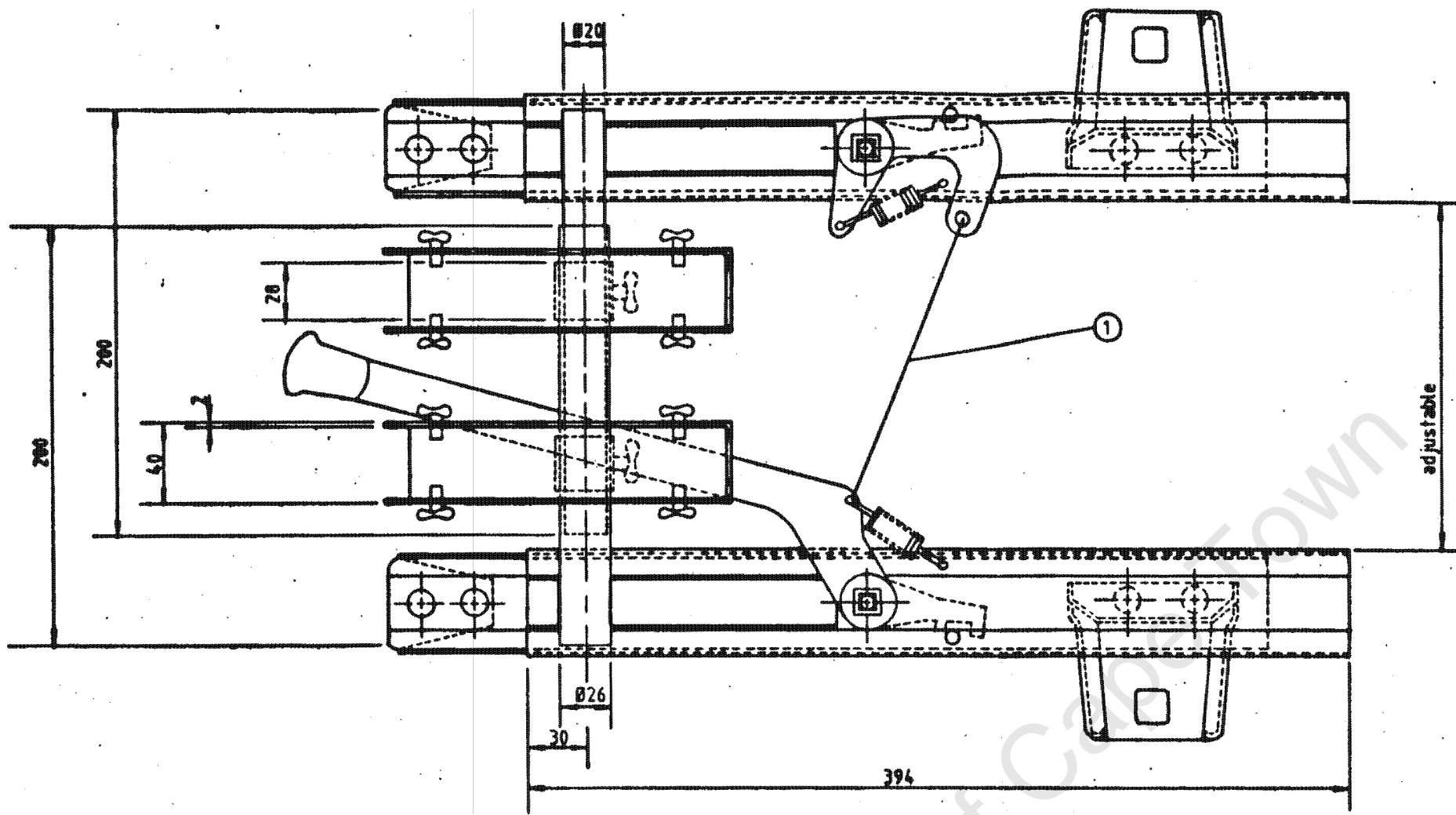
As shown in the photograph overleaf, the hydraulic circuit and the variable transformers were situated on a mobile trolley for ease of transportation and storage. The photograph shows the prototype mechanical driver in position. Although it is unclear, the pistons are on the brake and accelerator pedals. Note one of the two computer screens in front of the windscreen. The cycle being driven is indicated on this screen with a marker showing the vehicle's speed and position on the cycle.



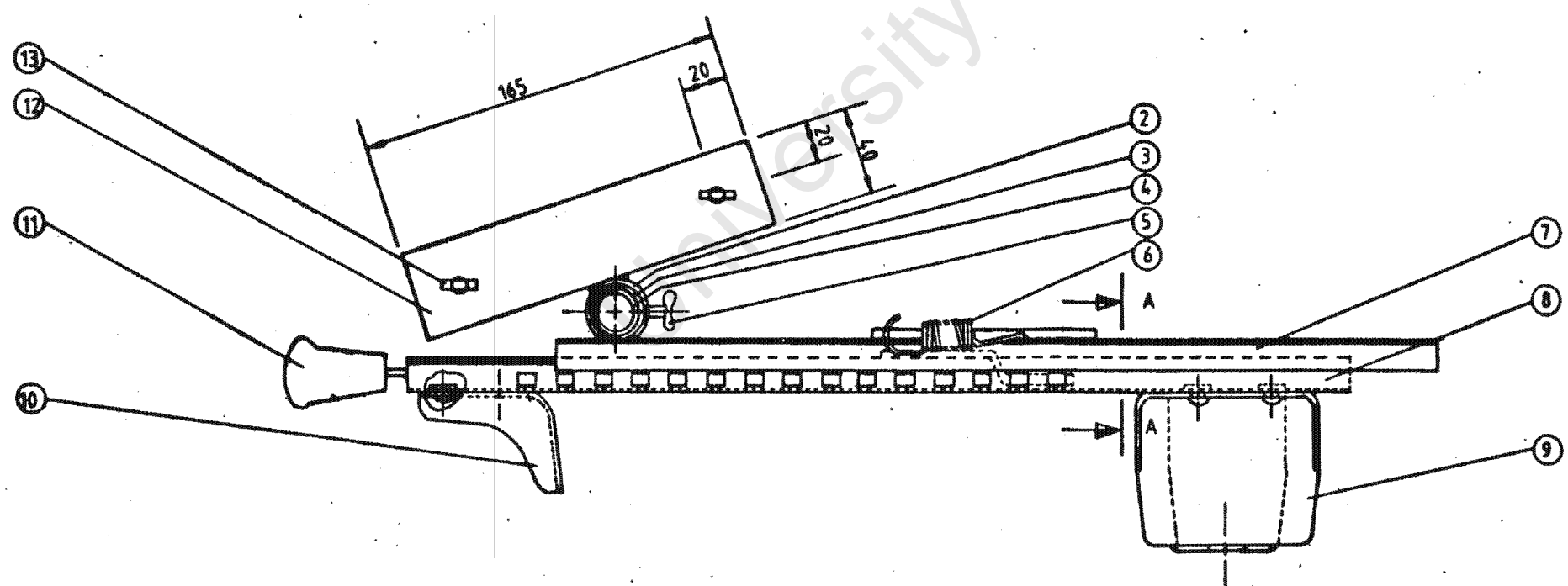
Figure 12

Photograph showing the prototype mechanical driver in position

When the vehicle is being driven by a human driver, he uses this screen to anticipate the driving pattern to be driven. The other computer screen is situated in the computer room in the background. This screen shows the same information as the other screen and is used by the computer programmer. Note also the cooling fan duct in front of the vehicle which directs cool air through the vehicle's radiator. The exhaust extraction duct is also visible next to the vehicle's rear wheel.



SECTION A-A



All dimensions in mm

PART NO	DESCRIPTION	NO OFF	REMARKS
15	BEARINGS	-	
14	BEARING RACE	-	
13	LOCATING SCREW	8	WINGED HEAD
12	PISTON HOLDER	2	
11	ADJUSTMENT HANDLE	1	
10	FRONT LOCATING FOOT	2	
9	REAR LOCATING FOOT	2	
8	BOTTOM RAIL	2	ALREADY IN CAR
7	TOP RAIL	2	
6	SPRING	2	
5	TIGHTENING SCREW	2	WINGED HEAD
4	CONNECTING TUBE	1	Ø24 x 200 mm
3	CONNECTING TUBE	1	Ø26 x 200 mm
2	LOCATING TUBE	1	Ø28 x 28 mm
1	CONNECTING WIRE	1	ADJUSTABLE LENG

UNIVERSITY OF CAPE TOWN
DEPARTMENT OF MECHANICAL ENGINEERING

MECHANICAL DRIVER

SCALE: 1:2	SHEET 1 OF 2
DATE: 6/11/87	MASTERS PROJECT
DRAWN BY: P.J. PRYOR	

As with the final design, feedback on the position of the accelerator piston was given by means of a potentiometer. The BBC computer indicated the position of the pedal on the screen as an integer between 0 and 100. The computer controlled the driver by means of the program described in Appendix B. The hydraulic circuit, motor, pump and solenoid valves were as specified in the final design and will not be described here again.

University of Cape Town

APPENDIX B - BBC COMPUTER PROGRAM CONTROLLING THE PROTOTYPE
MECHANICAL DRIVER

```

10     CLS
20     CLOSE#0
30     @%=&20209
40     *FX16,2
50     ?&FE62=&OF
60     ?&FE60=4
70     FOR I%=1 TO 2000:NEXT
80     ?&FE60=0
90     PRINTTAB(0,12)"Do you want to enter a new driving
      cycle? (Y/N)"
100    A$=INKEY$(10000)
110    IF A$='Y' THEN GOTO120 ELSE GOTO460
120    CLS
130    INPUTTAB(0,12) "What is the new driving cycle
      called",NAME$
140    CLS
150    INPUTTAB(0,12) "If new driving cycle is repetitive,
      give length of mini-cycle (in-seconds) and number of
      cycles", S,C
160    X=OPENOUT "CYCLE"
170    PRINT#X,NAME$
180    PRINT#X,S,C
190    DIM SPEED(S)
200    SSPEED=0:N%=0:SEC=0
210    IF SEC=S THEN GOTO350
220    INPUT"ENTER DURATION",DUR
230    SEC=SEC+DUR
240    IF SEC S GOTO410
250    IF DUR=999 GOTO950
260    INPUT"ENTER SPEED AT END OF DURATION",ESPEED

```

```
270   FOR INC=1 TO DUR
280   SPEED=SSPEED+(ESPEED-SSPEED)*INC/DUR
290   PRINT SPEED
300   N%=N%+1
310   SPEED(N%)=SPEED
320   NEXT
330   SSPEED=ESPEED
340   GOTO210
350   FOR N%=1 TO S
360   PRINT#X,SPEED(N%)
370   NEXT
380   CLOSE#X
390   GOTO550
400
410   CLS
420   PRINTTAB(0,12)"TOTAL DURATION EXCEEDS LENGTH OF CYCLE"
430   SEC=SEC-DUR
440   GOTO220
450
460   Y=OPENUP "CYCLE"
470   INPUT#Y,NAME$
480   CLS
490   PRINTTAB(0,12)"This driving cycle is called";NAME$;"If
    it is ok push space bar, if not push any key."
500   B$=GET$
510   IF B$=" " THEN GOTO520 ELSE GOTO10
520   INPUT#Y,S,C
530   DIM SPEED(S)
540   GOTO580
550   Y=OPENUP "CYCLE"
560   INPUT#Y,NAME$
570   INPUT#Y,S,C
580   P=1
590   REPEAT
```

```

600     INPUT#Y,A
610     SPEED(P)=A
620     P=P+1
630     UNTIL EOF#Y
640     CLS
650
660     PRINTTAB(0,12) "Piston position is
        at" ;ADVAL(2)*100/65536;" If this is ok press space bar
        to start cycle.":REPEAT UNTIL GET=32:CLS
670     DIST1=0.001:DIST2=0.001:DIST3=0.001:DIRN=0:TIME=0:Q=0:
        SIGMA%=0:RA%=0:SIGMA=0
680     NUMB=S*C
690     NUM=NUMB-1
700     ?&FE60=0
710     IF(TIME/100/S) C THEN GOT0910
720     ASPEED=ADVAL(1)*100/65536
730     N%=TIME/100-S*((TIME/100) DIV S)+0.5
740     TSPEED=SPEED(N%+1)
750     DIFF=(TSPEED-ASPEED)
760     DIST1=ABS(DIFF)
770     OUT%=DIST1
780     SIGMA%=SIGMA%+OUT%*OUT%
785     SIGMA=SQR(SIGMA%/NUM)
790     RA%=-RA%*(OUT% RA% OR OUT%=RA%)-OUT%*(OUT% RA%)
800     PRINTTAB(0,12)"THEORETICAL ";TSPEED
810     PRINTTAB(0,14)"ACTUAL      ";ASPEED
820     PRINTTAB(0,16)"POTENTIOMETER ";ADVAL(2)*100/65536
830     IF ABS(DIST1/DIST2) 1 THEN GOT0860
840     IF TSPEED=0 THEN GOT0980
850     PROCmoveacc(DIFF)
855     DIST3=DIST2
860     DIST2=DIST1+0.001
870     FOR WW%=1 TO 1000:NEXT
880     GOT0710

```

```
890 Procst111(1,1000)
900 GOTO860
910 CLOSE#Y
930 PRINTTAB(0,20)"STANDARD ERROR= "; SIGMA" Km/h"
940 PRINTTAB(0,22)"MAXIMUM ERROR= ";RA%" Km/h"
950 END
960
970
980 DEF PROCst111(X%,Y%)
990 IF Q 1 THEN GOTO1040
1000 ?&FE60=X%
1010 FOR I%=1 TO Y%:NEXT
1020 ?&FE60=0
1030 Q=Q+1
1040 ENDPROC
1050
1060 DEF PROCmoveacc(DIFF)
1070 Q=0
1075 ?&FE60=2
1080 posn%=ADVAL(2)
1090 newposn%=posn%+DIFF*65536/100
1100 REPEAT
1110 x%=ADVAL(2)
1120 dirn%=SGN(newposn%-x%)
1130 IF dirn%=0 THEN GOTO1110
1140 IF dirn% 0 THEN GOTO1150 ELSE GOTO1190
1150 ?&FE60=6+2*dirn%
1160 FOR N%=1 TO 220:NEXT
1170 ?&FE60=0
1180 GOTO1230
1190 ?&FE60=6+2*dirn%
1200 FOR N%=1 TO 400+ABS(ADVAL(2)-newposn%)/100
1210 NEXT
1220 ?&FE60=0
```

```

1230 PRINTTAB(0,18)"AD(2)-nposn ";ABS(ADVAL(2)-newposn%)
1240 UNTIL ABS(ADVAL(2)-newposn%) 1300
1250 FOR N%=1 TO 170:NEXT
1260 IF ABS(ADVAL(2)-newposn%) 3000 THEN GOTO1110
1270 ENDPROC

```

The BBC computer program is briefly described here.

- 10 - 50 Setting initial conditions
- 60 - 80 Withdrawing accelerator piston to zero position
- 90 - 450 Entering new driving cycle onto disc at one second intervals. This section can be by-passed if current cycle on computer disc is required to be run again
- 460 - 650 Transferring either new cycle or current cycle from disc into an array in computer memory
- 660 - 700 If the operator is satisfied with the piston positions, all initial variables are set and the cycle is started
- 700 - 900 Computer reads theoretical speed from cycle and actual speed from the dynamometer, computes the difference and sends a signal to either the accelerator or the brake solenoid valve. The speed error from each sample is summed in a memory
- 910 - 950 At the end of a driving cycle, the cycle analysis is given showing maximum error and standard error
- 980 - 1050 Procedure to depress or release the brake pedal

1060 - 1270 Procedure to depress or release the accelerator pedal to a value at which the speed error will be kept to a minimum.

The emergency stop button was allocated to key f9 by using this instruction.

*KEY9?&FE60=10||M

On pressing key f9, both pistons retract thus releasing both the accelerator and brake pedals.

University of Cape Town

APPENDIX C - DESCRIPTION OF THE ECE DRIVING CYCLE

The following is a description of the ECE urban driving cycle as used by the SABS with reference to figure 13.

- a stationary idle for 11 seconds in neutral
- b accelerate from 0 to 15 km/h in 4 seconds in first gear
- c remain at 15 km/h in first gear for 8 seconds
- d decelerate from 15 km/h to approximately 8 km/h in 2 seconds in first gear
- e declutch and decelerate to standstill in 3 seconds
- f stationary idle for 21 seconds in neutral
- g accelerate from 0 to 15 km/h in 5 seconds in first gear
- h change from first to second gear in 2 seconds at 15 km/h
- i accelerate from 15 to 32 km/h in 5 seconds in second gear
- j remain at 32 km/h in second gear for 24 seconds
- k decelerate from 32 km/h to approximately 8 km/h in 8 seconds in second gear
- l declutch and decelerate to standstill in 3 seconds
- m stationary idle for 21 seconds in neutral
- n accelerate from 0 to 15 km/h in 5 seconds in first gear
- o change from first to second gear in 2 seconds at 15 km/h
- p accelerate from 15 to 35 km/h in 9 seconds in second gear
- q change from second to third gear in 2 seconds at 35 km/h
- r accelerate from 35 to 50 km/h in 8 seconds in third gear
- s remain at 50 km/h for 12 seconds in third gear
- t decelerate from 50 to 35 km/h in 8 seconds in third gear
- u remain at 35 km/h for 13 seconds in third gear
- v change from third to second gear in 2 seconds - speed decreases to approximately 32 km/h

- w decelerate from 32 to approximately 8 km/h in 7 seconds in second gear
- x declutch and decelerate to standstill in 3 seconds
- y stationary idle for 7 seconds in neutral

The complete urban cycle comprises of two of the above operating sequences (operated consecutively).

Note that this is the standard cycle as it appears for a vehicle with a manual transmission. When testing vehicles with an automatic transmission, the "drive" position should be used throughout the test and the gear changes must be as close as possible to the cycles' gear changes. Declutching is impossible with automatic vehicles so the vehicle must be decelerated normally where declutching occurs on the cycle.

A speed tolerance of 1 km/h above or below the theoretical speed is allowed except during phase changes where a larger tolerance is permissible. At these points the duration of the excursion must not exceed 0,5 seconds on any single occasion. A time tolerance of $\pm 0,5$ seconds is allowed.

Source: ECE method of measuring the fuel consumption of motor vehicles, Document TRANS/SCI/WP29/R.204 Annex 9, Table 4.

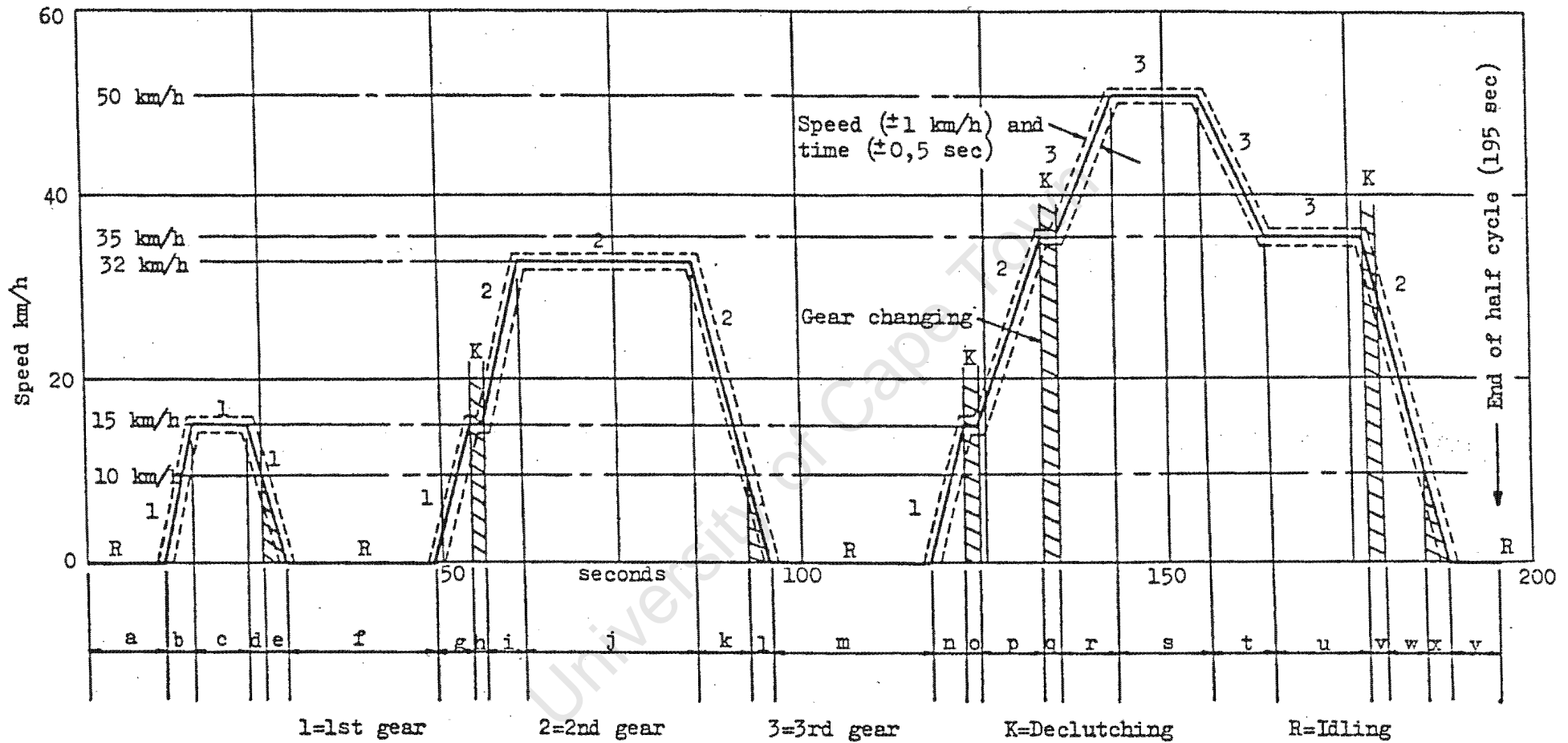


Figure 13 Half of the urban driving cycle as used by the SABS.

APPENDIX D - COST ANALYSES1. Cost Analysis of the Solution Adopted (January 1987)1.1. Hydraulic circuit

Tank	R	90,00
1 Filter	R	310,00
4 m Bundy tube @ R6,23/m	R	24,92
8 m Rubber hose @ R12,50/m	R	100,00
3 litres Hydraulic oil @ R7,50/litre	R	22,50
16 Connectors @ R3,89 each	R	62,24
1 Tee connector @ R11,44 each	R	<u>11,44</u>
Sub total	R	<u>621,10</u>

1.2. Hydraulic solenoid valves

2 Bosch NG6 No 0 810 090 129 directional control valves @ R533,00 each	R1	066,00
2 Subplates @ R111,40 each	R	<u>222,80</u>
Sub total	R1	<u>288,80</u>

1.3. Electrical components

4 MJE 3055 transistors @ R10,56 each	R	42,24
4 BC 109 transistors @ R0,78 each	R	3,12
4 0,1 F capacitors @ R0,70 each	R	2,80
1 Potentiometer @ R1,31 each	R	1,31
500 x 100 mm Veroboard	R	48,50
5 m Computer ribbon cable @ R4,80/m	R	24,00
1 Edge connector @ R2,50 each	R	2,50
1 Cigarette lighter socket @ R3,29	R	3,29
Resistors and diodes - negligible		
Sub total	R	<u>127,76</u>

1.4. Frame

Labour 3 hours @ R40/hour	R 120,00
4 m 25x25 mm mild steel tubing @ R2,75/m	R 11,00
0,5 mm 016 mild steel bar @ R1,52/m	<u>R 0,76</u>
Sub total	<u>R 131,76</u>

1.5. Pistons

Labour 2 hours @ R40/hour	R 80,00
Steel stock - negligible	

1.6. A.C. Motor and Pump

2,2 kw a.c. motor	R 400,00
Pressure and flow compensation hydraulic pump	<u>R1 200,00</u>
Sub Total	<u>R1 600,00</u>

1.7. Computer

IBM-compatible personal computer with printer	R3 500,00
---	-----------

1.8. General

Nuts, bolts, plates, tools, spares, installation and testing plus unaccounted costs (+- 30% total costs)	R2 200,00
--	-----------

Total Cost of System

1.	Hydraulic circuit	R 621,00
2.	Hydraulic solenoid valves	R1 289,00
3.	Electrical components	R 128,00
4.	Frame	R 132,00
5.	Pistons	R 80,00
6.	A.C. motor and pump	R1 600,00
7.	Computer and printer	R3 500,00
8.	General	<u>R2 200,00</u>
	Total excluding tax	<u>R9 550,00</u>

Not all the above equipment was purchased for the prototype. Some equipment was available to the author, e.g. d.c. motor and pump, BBC computer, power pack, labour, etc.

Thus by using substitute parts and "free" workshop labour from UCT, the author actually "saved" R6 850,00.

i.e. in January 1987, the prototype cost R2 700,00 to build which is within the budget set by the student in the criteria.

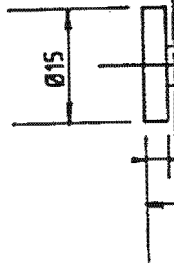
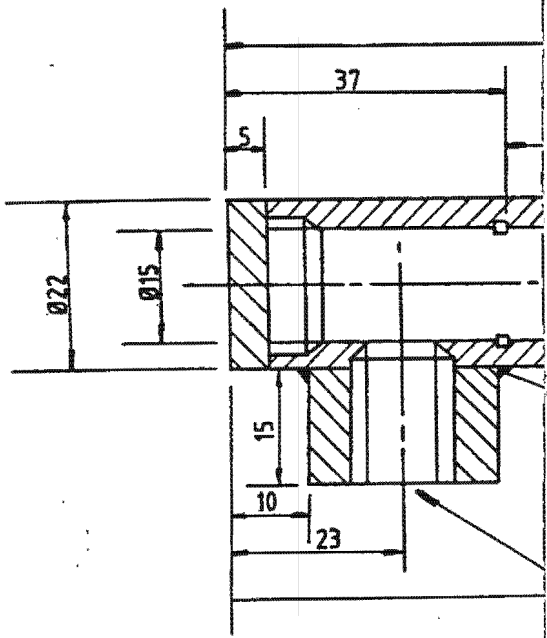
2. Cost Analysis of the "No Cost Limit" Solution

2.1.	2 Bosch NG6 No. 0811404029 closed loop proportional valves @ R2 900,00 each	R 5 800,00
2.2.	All electronics associated with the above valves including; PID controller, linear transducer, power supply, relay cards, amplifying card for the linear transducer, comparator card and card holders	R13 000,00
2.3.	2,2 kw a.c. motor	R 500,00
2.4.	Type S, size G gear pump no. 0510725013	R 500,00
2.5.	2 cylinders - bore 40mm, rod 20mm, stroke 100mm, with low friction seals and spherical bearing male clevis @ R375 each	R 750,00
2.6.	Accumulator charging valve	R 800,00
2.7.	2 filters @ R450,00 each	R 900,00
2.8.	Tank	R 220,00
2.9.	Accumulator	R 490,00
2.10.	Safety relief valve	R 140,00
2.11.	IBM-compatible computer with analogue to digital converter	R 3 500,00

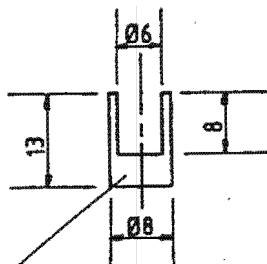
2.12. General - including connectors, tubing, fittings, temperature and volume switches, level indicator, pressure gauge, needle valve, software for the computer	<u>R 1 500,00</u>
Total cost of system excluding GST	<u>R28 100,00</u>

Source: Hyflo Transvaal (Pty) Ltd

University of Cape Town



drill and tap 1/4" BSP
thread length = 15mm



8

9	SPRING	1	
8	VALVE PISTON	1	SILVER STEEL
7	VALVE	1	BRASS
6	M12 BOLT	1	ADJUSTABLE
5	PISTON RAM	2	SILVER STEEL
4	BOSS	4	THREADED
3	CAP WITH LOCATION SPIGOT	4	REMOVABLE
2	PISTON	2	L.C. STEEL
1	CIRCLIP	4	
PART NO	DESCRIPTION	NO OFF	REMARKS

UNIVERSITY OF CAPE TOWN
DEPARTMENT OF MECHANICAL ENGINEERING

MECHANICAL DRIVER

SCALE: 1:1

SHEET 2 OF 2

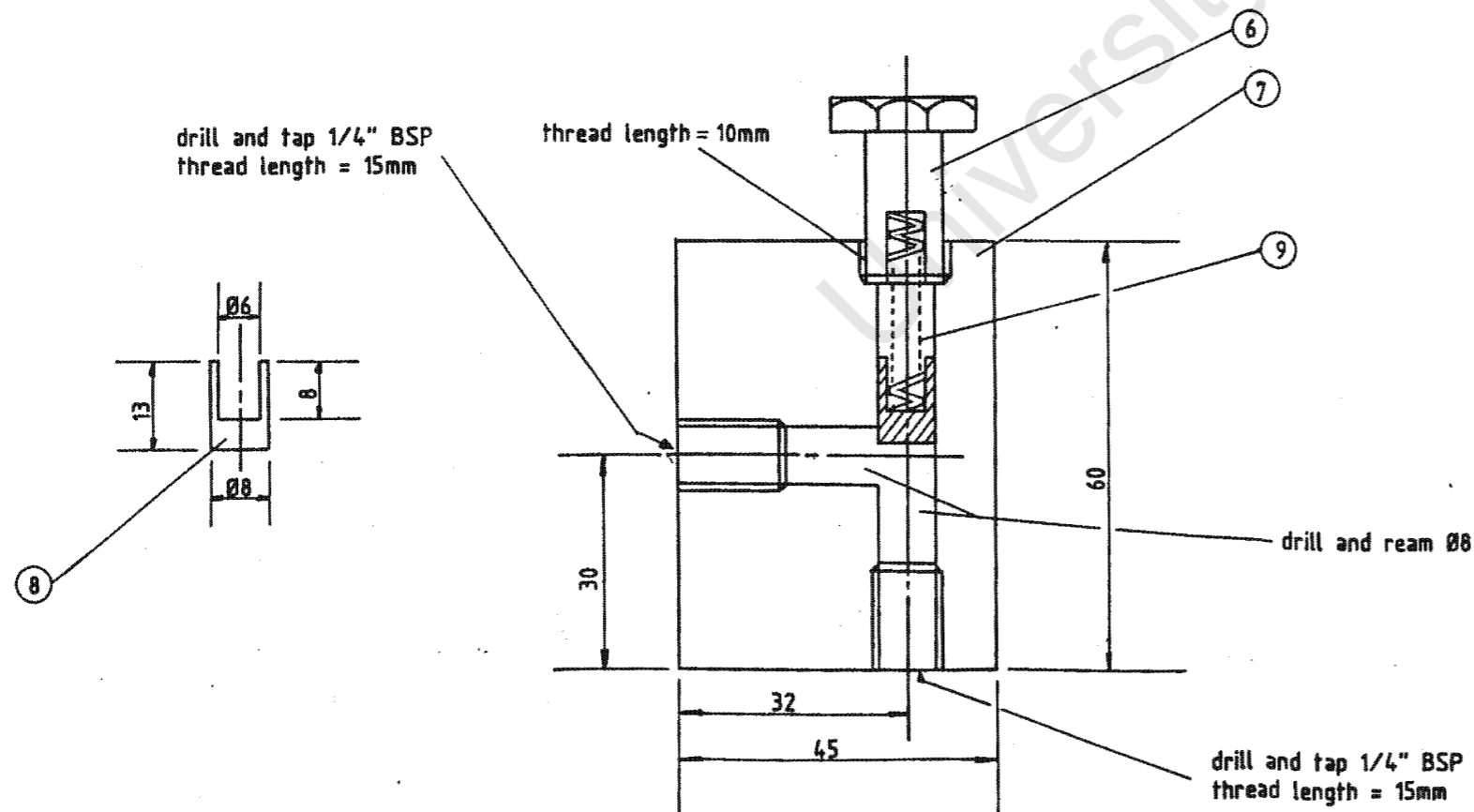
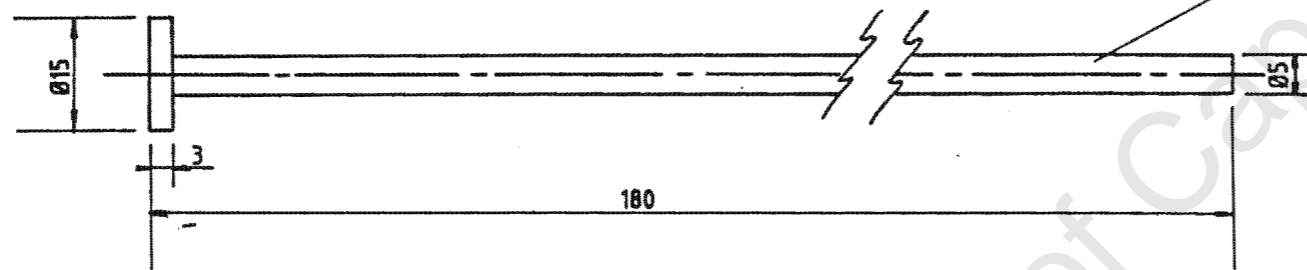
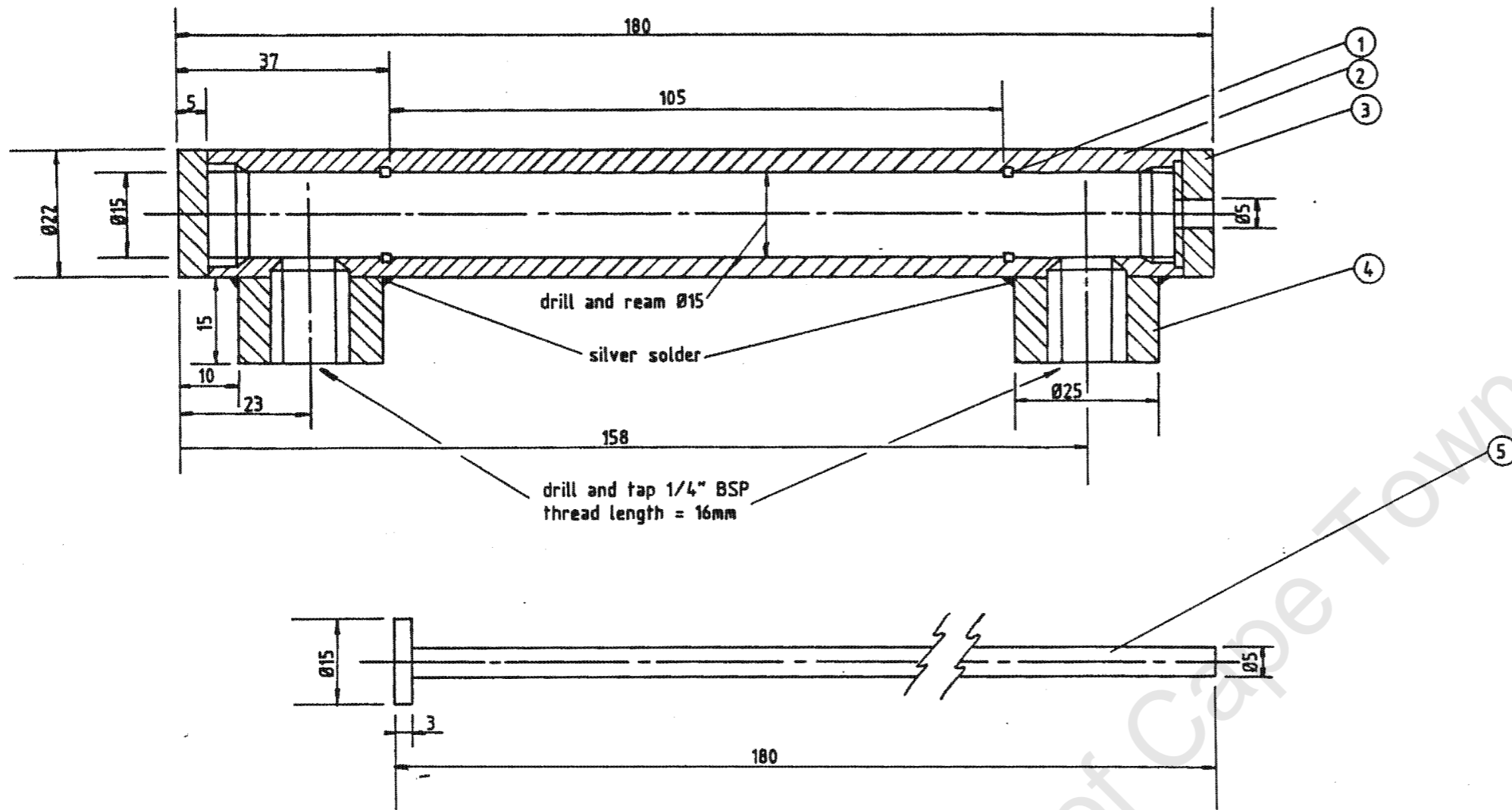
DATE: 6/11/87

DRAWN BY: P.J. PRYOR

MASTERS PROJECT

APPENDIX E - MAIN DRAWINGS

University of Cape Town



All dimensions in mm

PART NO	DESCRIPTION	NO OF	REMARKS
9	SPRING	1	
8	VALVE PISTON	1	SILVER STEEL
7	VALVE	1	BRASS
6	M12 BOLT	1	ADJUSTABLE
5	PISTON RAM	2	SILVER STEEL
4	BOSS	4	THREADED
3	CAP WITH LOCATION SPIGOT	4	REMOVABLE
2	PISTON	2	L.C. STEEL
1	CIRCLIP	4	

UNIVERSITY OF CAPE TOWN
DEPARTMENT OF MECHANICAL ENGINEERING

MECHANICAL DRIVER

SCALE: 1:1

SHEET 2 OF 2

DATE: 6/11/07

DRAWN BY: P.J. PRYOR

MASTERS PROJECT