Plasto-Hydrodynamic Polymer Coating Of Fine Wires

By

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This thesis is submitted as a fulfilment of the requirement for the award of Master of Engineering (MEng) by research to the

Dublin City University

Sponsoring Establishment:-

Dublin City University Post Graduate And Research Studies Committee

August 1989

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Declaration

I declare that all unrefered to work described in this thesis is entirely my own, and that no portion of the work contained in this thesis has been submitted in support of any other degree or qualification of this or any other institution of learning.

Signed Roger E Lamb

Roger E. Lamb

August 1989

Abstract

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R.E. Lamb

This project outlines the design and commissioning of a multi-purpose drawing bench and pressure die chamber so as to coat fine wires. The pressure chamber was designed along similar lines to the pressure chambers used by previous researchers for Plasto-hydrodynamic die-less drawing of wire. The commissioning and future safe operation of the drawing bench have been described.

The experimental proceedures and methods have been outlined. Investigations into a wide range of drawing conditions have been carried out. These include the polymer coating of wires of two different types of material, wires with three diameters, utilising three different dies and two different polymers. Results from these tests have been presented graphically. From the results contained in these graphs conclusions have been drawn and an outline for further research has been proposed.

Acknowledgements

The author wishes to thank Professor M.S.J. Hashmi for his supervision and guidence during the period of this research. He would also wish to convey his thanks to Mr. Tommy Walsh and all the other technicians in the college for their practical ideas and good technical manufacturing of the drawing bench.

He wishes to thank especially all his brothers and sisters in the Lord Jesus Christ who is his Saviour and God for all the help and encouragement that they have been in the writing of this thesis.

Nomenclature

m	Mass (kg)
ω	Angular velocity (rad/s)
r	Radius (m)
a	Acceleration (m/s^2)
N	Force (N)
σ	Tensile stress (N/mm^2)
σ_1, σ_2	Principal stresses (N/mm^2)
σ_x, σ_y	Co-ordinate stresses (N/mm^2)
τ	Shear stress (N/mm^2)
ω_s	Natural frequency of tranverse vibration of a shaft due to beam inertia alone (rad/s)
ω_1, ω_2	Natural frequency of transverse vibration for each mass load on shaft alone (rad/s)
b, d, l, x	Length (m)
I	Second Moment of Area (m^4)
E	Modulus of Elasticity (N/mm^2)
M_l	Mass per unit length of shaft (kg/m)
a, b	Distance from end of shaft (m)
J	Polar moment of inertia (kgm^2)
d	Diameter (mm)
ρ	Density (kg/m^3)
k	Radius of gyration (m)

M	Moment (Nm)
d_m	Mean bearing diameter (mm)
D	External diamter of bearing (mm)
v	Velocity (m/s)
f	Rotating speed (rev/s)
n	Revolutions per minute (RPM)
ν	Kinematic viscosity (mm^2/s)
f_o	Bearing factor
Q	Heat loss (W)
U	Thermal Conductivity ($W/m^{2\circ}C$)
A	Area (m^2)
Δt	Temperature differential ($^\circ C$)
Q'	Heat loss per unit length (W/m)
U'	Heat transfer per unit length of cylinder ($W/m^\circ C$)
k_i	Thermal conductivity of material ($W/m^\circ C$)
h_a, h_b	surface heat transfer co-efficient ($W/m^{2\circ}C$)

Chapter 1

Introduction

1.1 Development Of Plasto-Hydrodynamic Wire Drawing & Coating

The wire drawing process has traditionally been the drawing of a circular wire through a continuously varying tapered die. The purpose of the wire drawing is to gradually reduce the wire to a specified size and at the same time to obtain the required metallurgical properties, including surface finish and a high degree of repeatability.

In general, wire is drawn cold and hence a quite substantial drawing force is required. For this reason, the most common drawing dies used are made out of tungsten carbide and for finer diameters of wire, dies made out of diamond are used. Due to the high loading of the dies during wire drawing, lubrication is essential. There are two main types of lubrication used at present and a third type which is really only in its experimental stages of development. These are :-

1) "Wet Drawing":- the wire and drawing apparatus are submerged in a bath of lubricant. This method of

lubrication is predominantly used with wires of less than 0.5 mm and produces a good surface finish.

2) "Dry Drawing":- carried out on wires with a diameter greater than 0.5 mm. Before drawing the wire is passed through a box containing powdered calcium or sodium sterate soap. On a majority of occasions the wire is coated with an alkaline solution such as borax or a lime liquid before entering the box. This is to increase the adhesion of the soap to the wire. This type of lubrication has been termed "quasi-hydrostatic"(1) as the film thickness generated is greater than that produced using boundary lubrication techniques.

3) "Hydrostatic Lubrication":- In this case a high pressure is produced by viscous action between the wire and the lubricant in a tube through which the wire passes. This pressure is of the order of the yield strength of the metal being drawn. When the wire passes through the die the pressurised lubricant remains on the wire surface and hence reduces the die wear dramatically.

In both "wet" and "dry" drawing, friction between the wire and the die is of the boundary type, ie, metal to metal contact. This occurs even though there is lubricant present. On the other hand, hydrodynamic lubrication produces a continuous lubricant film in the die region, provided the wire is drawn at a high enough speed.

Wistreich (2) has established that greater drawing speeds could be produced provided the die friction could be reduced. The conventional wire drawing processes are at a very advanced level and there is not likely to be any further significant breakthrough. This leaves the way open for investigation into hydrodynamic wire lubrication.

1.2 Historical Background Of Hydrodynamic Lubrication

The wire drawing process is simple in its basic form and has been carried out on an experimental basis. Initially there was little theoretical basis for the way the wire was drawn. This was sufficient in the past but as the demands of industry have increased, a greater knowledge of the wire production process is required. This includes the following areas:-

a) Reduction of drawing time while maintaining wire quality.

b) High reduction in area per pass.

c) Heat dissipation of the wire during drawing (keeps wire at low temperatures.)

d) Improvement of surface finish.

e) Reduction of drawing costs by:-

i) Reducing drawing times;

ii) Eliminating wire preparation treatment;

iii) Reducing the number of interpass heat treatments;

iv) Reducing machine maintenance time required due to excessive die wear.

Hydrodynamic lubrication was first investigated by Christopherson and Naylor[3]. The idea was first put forward by MacLellon and Cameron[4] in 1943. Christopherson and Naylor employed a long tube (about 0.8m long) with a small wire to tube radial clearance approximately 0.04 - 0.05 mm. as in Fig.1. The die at the end of the tube prevented the lubricant flowing out of the tube. The lubricant used was oil because a good deal of rheological data was known about oil. The wire, when being drawn, creates viscous forces which develops a pressure in the order of the yield strength of the material being drawn. The pressurised lubricant then completely separates the wire from the die, preventing metal to metal contact. Christopherson and Naylor experimentally showed this to be so and that the wire started deforming before it entered the die. Along with these encouraging results there were drawbacks which prevented it being taken up by industry. Some of these drawbacks were that the tube had to be in a vertical plane and that it needed a leader wire, but since hydrodynamic lubrication did not begin at start up, die wear was evident during this period of drawing.

Following on from these findings it was decided to go back to drawing, using dry soap lubrication as it is a very good boundary lubricant. Because of this the drawing tube could be shortened dramatically to approximately 50 mm. in length. Wistrreich(5) carried out experiments with a die of this description and found the following results:- drawing speed, temperature, and tube gap had a direct effect on the property of the film thickness developed. He also noted that oil produced a thicker film thickness than soap. Leading from these and other ideas the (B.I.R.S.A.) dry soap nozzles were designed(6); (see Fig.2). This type of die had one major drawback; when the moisture content of the soap was high the soap's lubricating properties deteriorated. Consequently a double die system, using externally pressurised oil, was developed (see Fig.3). It had on the inlet an "ironing" die which acted as a seal and reduced the wire by about 5%[7]. The ironing die, though, produced more problems then it solved as it was unlubricated and a high pressure pump was required to produce the required oil pressure between the dies.

The double die system as a whole seemed viable and was developed by Orlov, et al[8] using an approach die equal to the nominal diameter of the wire (see Fig.4). The pressure was developed by the oil passing through the pressure die. This removed the need for a high pressure pump because the wire motion transported the lubricant in the chamber and hence, built-up pressure was produced by the exit cone from the pressure die and the entry cone to the drawing die. This pressure was then great enough to produce hydrodynamic lubrication. It was claimed that this method reduced die wear by 500% and reduced power consumption by 48%, though there was a lack of substantial evidence to support this fact.

1.3 Introduction of Polymer Melt As a Lubricant In Wire Drawing

Polymers were first used as lubricants in deep drawing and hydrostatic extrusion. They were chosen because of the radically differing characteristics from either soap or oil. One major difference between oil and polymer characteristics is that viscosity of polymers vary less than that of oils over the same temperature range.

The use of a polymer melt as a lubricant in wire drawing was first suggested by Symmon and Thompson[9], who investigated the adherence of polymer coats onto wire. There was some hydrodynamic lubrication achieved but not as much as expected. Both Stevens[10] and Crampton[11] conducted experiments which showed that polymer coating of wire was possible, depending on the temperature, viscosity of the polymer and drawing speed of the wire. The experiments they carried out reduced the cross-sectional area of the wire. They also noted that the polymer coat thickness on the wire decreased as the drawing speed increased. The apparatus used is shown in Fig.5 and was a modification of the Christopherson tube. It required a leader wire. It was also noted[12] that polymers initiated coating of wire at speeds as low as 0.1 m/s.

Parvinmehr[13] carried out similar experiments to Crampton's but used two different types of pressure tube in which the smallest diameter of the tube was greater than the initial diameter of the wire being drawn. They had no end die and this was because Crampton and other reseachers had previously noted that deformation started to occur before the entrance to the die. The two pressure tubes he carried his experiments out on were of stepped and tapered bored nature, (see Fig.6 & 7). The results he obtained showed that hydrodynamic lubrication was achieved and that polymer coating thickness varied with wire drawing speed, the polymer used and with the polymer temperature. The nominal diameter of the wire he used was 1.6 mm.

1.4 Scope of Present Work

Wire coating with a polymer at present is carried out using a double die extrusion technique in which the polymer is extruded over the surface of the wire which is being drawn. This works well for diameters of wire down to 0.4 mm with a coating thickness of 0.2 mm. At present wire with a diameter of less than 0.4 mm are simply dipped in a bath of molten polymer. This does not give a very even coat thickness and is not practical in a large scale production environment. This smaller sized wire is utilized in medical electronics and could be used for telecommunication and computing applications.

As a possible solution to this problem, this research is a continuation of the work of Stevens, Crampton and mostly Parvinmehr who had a die with a diameter greater than that of the wire. The main difference is that the diameter of the wire used by the aforementioned reseachers was about 1.6 mm and the wires on which experiments were carried out on in this investigation were of diameters ranging between 0.3 to 0.03 mm.

The scope of the present design and research is to :-

a) Design an experimental drawing bench to facilitate plasto-hydrodynamic drawing and coating of fine wire with the die having a greater diameter than the initial diameter of the wire.

b) Investigate the coating thickness, uniformity, continuity and quality on the fine wires with a polymer, if possible while altering the following variables:-

1) Temperature of the polymer melt;

2) Variation of the drawing speed;

3) Variation in the diameter of the pressure tube and die itself.

c) Discuss the viability of the process and its limitations in relation to practical applications and results from previous investigations.

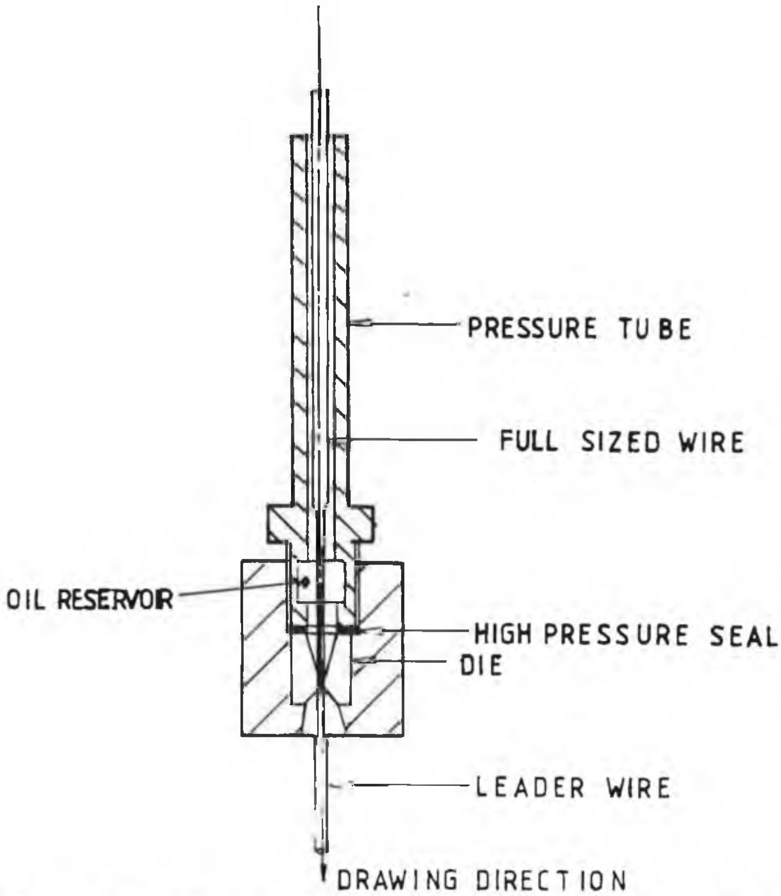


FIG. 1 TYPICAL CHRISTOPHERSON TUBE ASSEMBLY

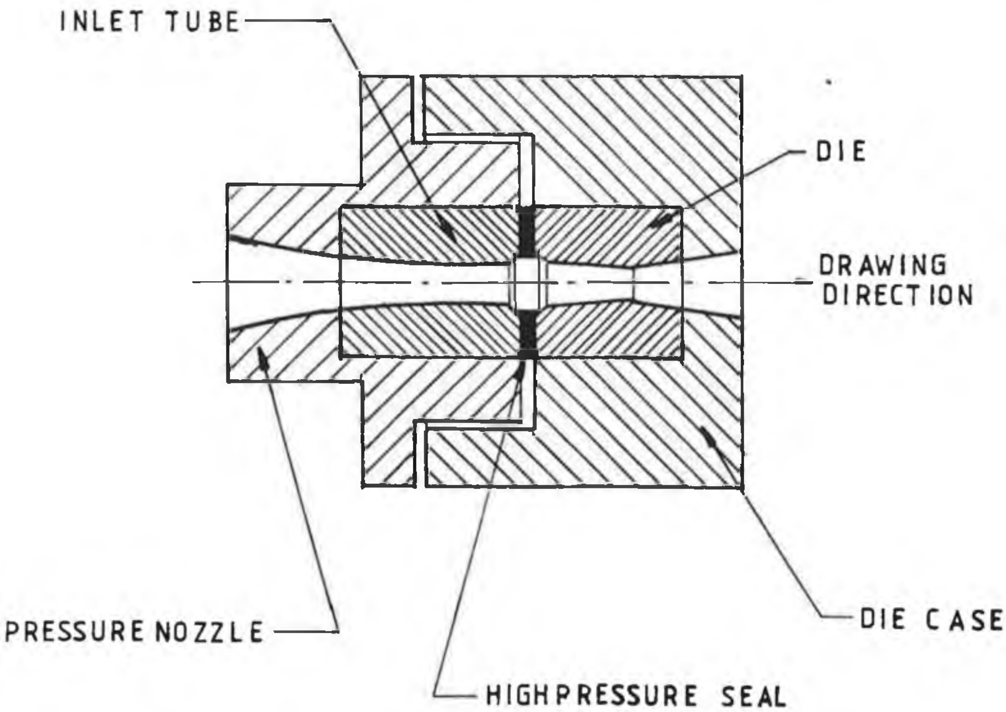


FIG. 2 NOZZLE - DIE UNIT (BIRSA)

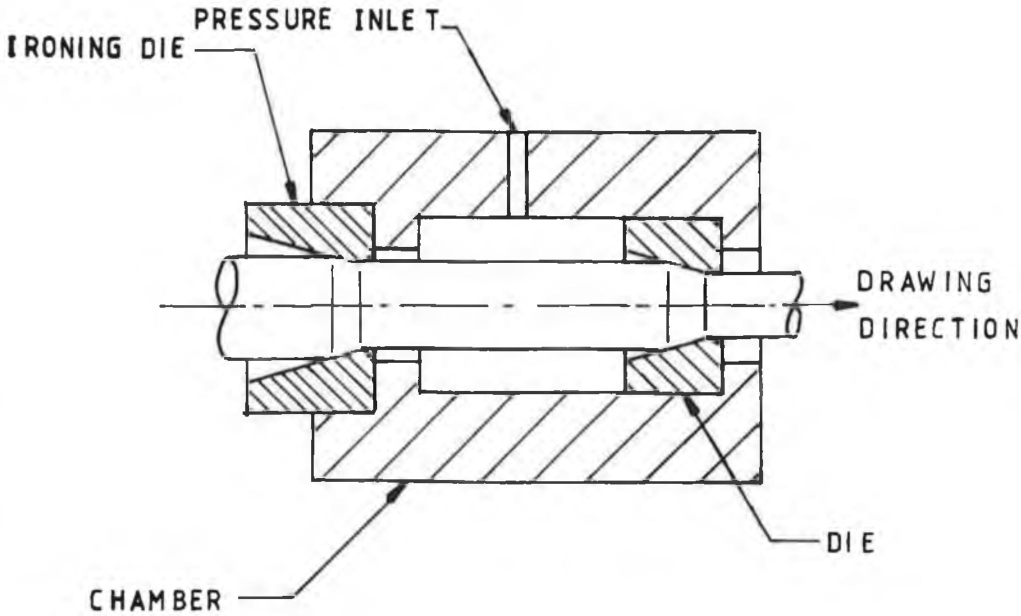


FIG. 3 PRESSURIZED CHAMBER

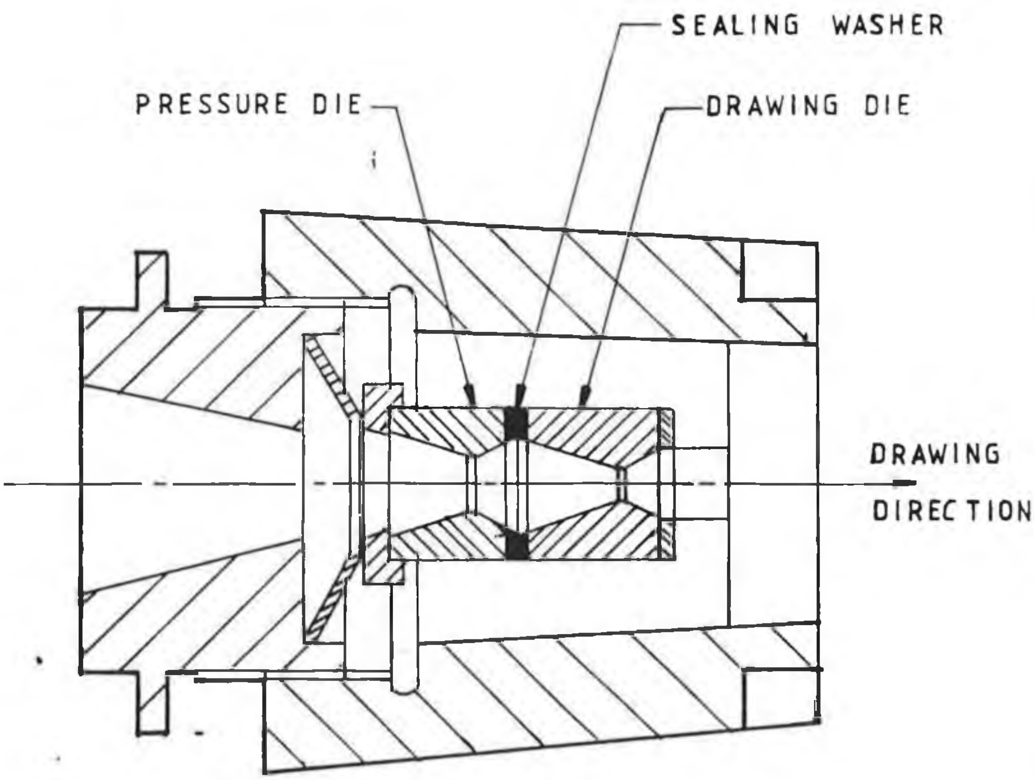


FIG. 4 DOUBLE DIE UNIT

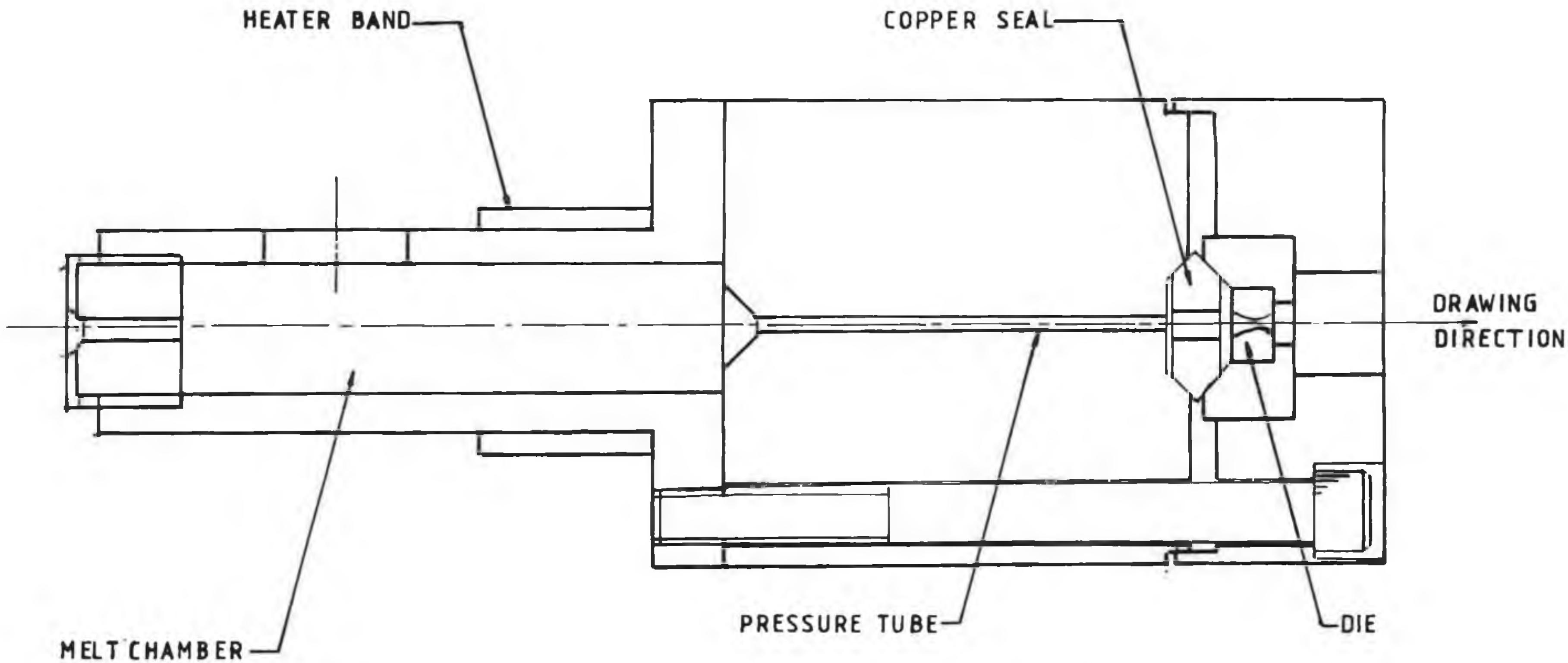


FIG.5 PRESSURE TUBE - DIE ARRANGEMEMT

FIG. 6 STEPPED BORE REDUCTION UNIT

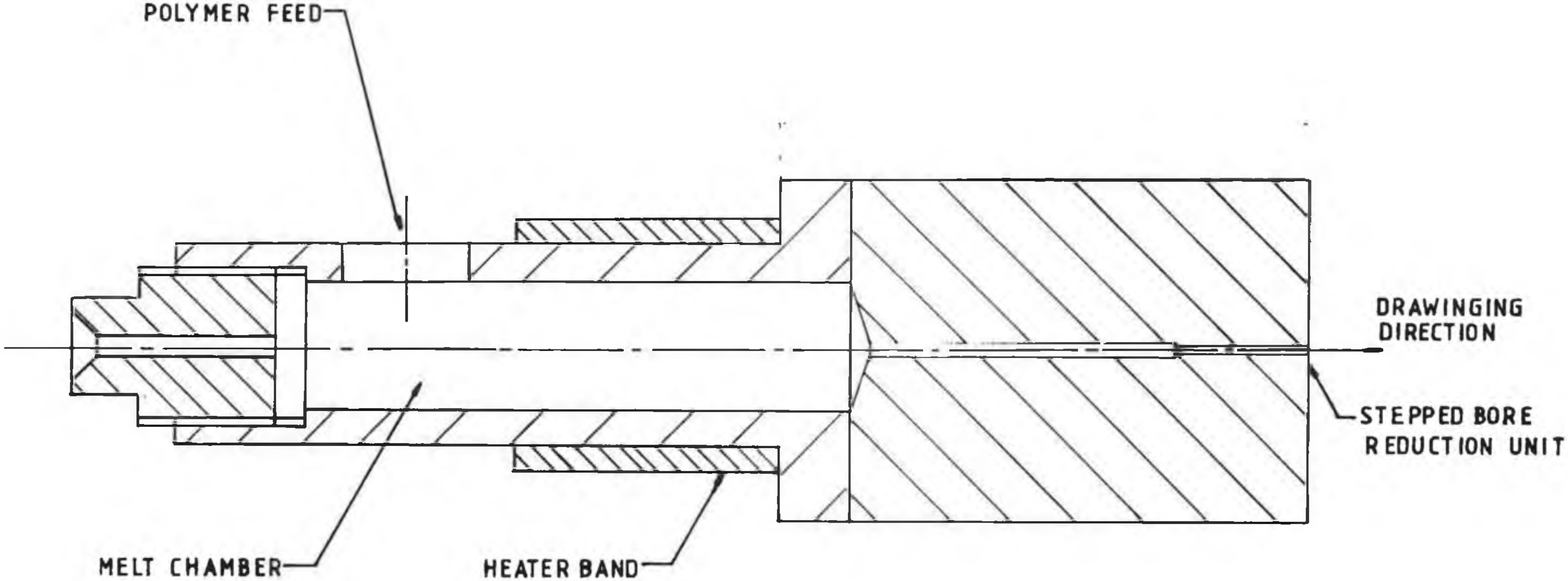
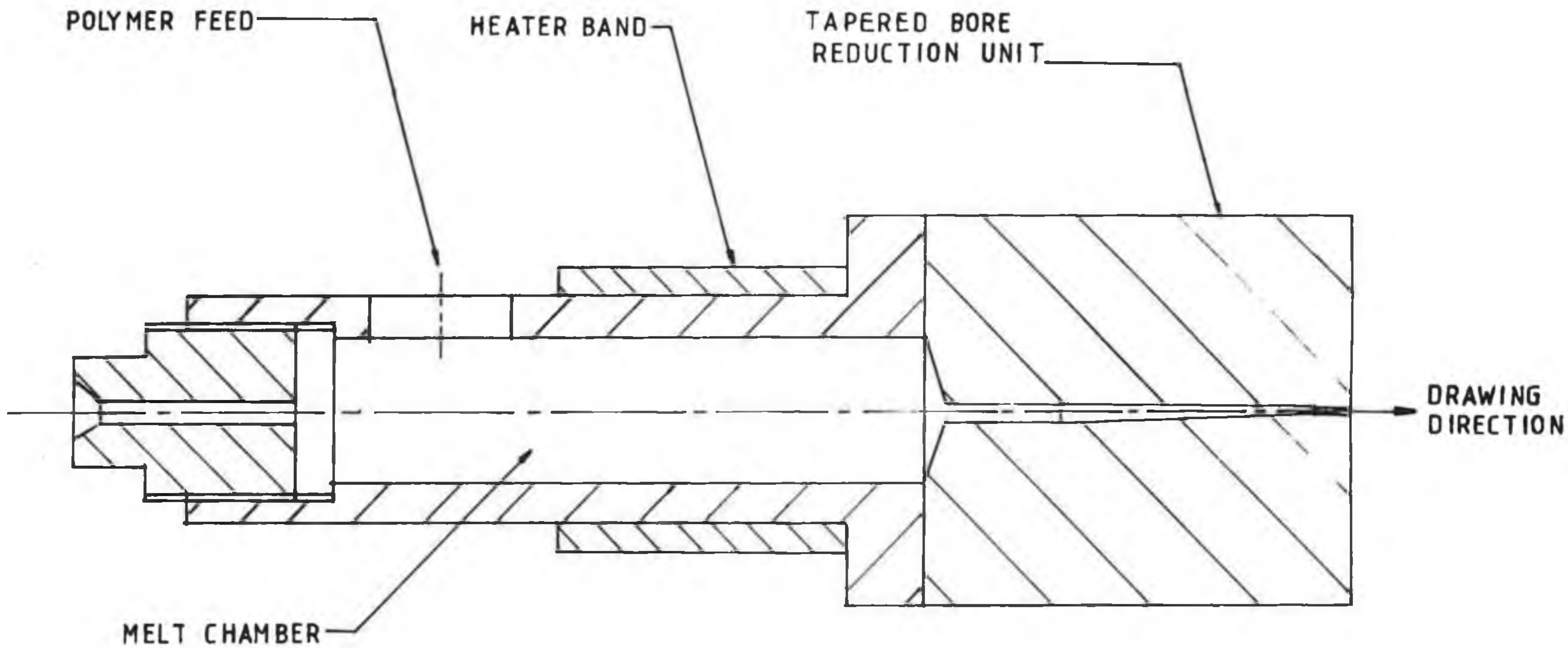


FIG. 7 TAPERED BORE REDUCTION UNIT



Chapter 2

Design Of The Drawing Bench

2.1 Design Specifications

The drawing bench was designed to be a multi-purpose, multi-user facility. It is to enable as many researchers as possible to use the bench with minimum alterations to it.

The drive train for the drawing bench should enable wire drawing at any speed between 0.05 to 20 m/s. The maximum drawing load for the bench should be 500 N at a drawing speed of 4 m/s. The operator should be able to monitor the drawing speed. It will be necessary to design the drawing bench so that wire which originates from two separate drawing chambers can be drawn onto the same bull block (at different times) with minimal alterations to the drawing bench.

The electricals for the bench are to be designed so as to allow multi-user facilities with associated interlocks so that equipment cannot be turned on without its control sensor to monitor the process.

The pressure die chamber (specific to this research) is to be designed along the same lines as Crampton's as far as possible with the exception that the die diameter is fractionally greater than the nominal wire diameter. The design is to have the facility of drawing multiple strands of wire through the die chamber with minimal alterations when the system is designed to draw a single strand of 0.03 mm diameter wire. The die wire clearance dimensions are to be as close as technically reasonable to those adopted by Crampton but on a reduced scale. The die chamber is to be capable of being heated to 400 ^{o}C so as to facilitate experimentation with polymers which have higher melting points.

The drawing bench structure is to allow easy access to the drawing block. It is to support all electrical equipment and ensure that the drive train is rigid. It is to contain a surface on which experiments can be mounted.

2.2 Design Of The Drive Train

In the light of the large range of drawing speeds required (0.05 to 20 m/s) it was decided to approach the problem in a multiplicity of ways. Each method would only produce a fraction of the required overall range of drawing speeds but combined together could produce the desired result.

The method decided upon was as follows :-

1) Create a variable speed motor;

2) Use a gearbox;

3) Use various sizes of bull block.

2.2.1 The Variable Speed Motor

The variable speed motor was produced using a standard 3 phase, 4 pole squirrel cage motor and a variac with a frequency range of 5 to 90 Hz. This was estimated to give the motor an operating speed range of between 150 - 2800 RPM, but in fact gave a speed range of 100 - 2600 RPM. The motor operating with these speed ranges gave a ratio of speeds in the order of 26.

The advantages of using a variac control system are as follows :-

a) The motor's acceleration and deceleration times can be altered so that on start up the load on the wire can be reduced and hence the fine wires are less likely to break.

b) There is no need to use a clutch.

c) The motor's direction of rotation can be altered easily.

d) The electric motor can be overspeeded.

e) The variac could power-boost the motor to 115% of the motor's rating for a short period of time.

The disadvantages of this system are :-

a) The electric motor running at low speeds needs to have a forced air-flow over it.

b) The motor torque increases linearly up to the normal working speed of the motor (1450 RPM, in this case) and then the output torque of the motor decreases fractionally while rising to the maximum speed at which the inverter can drive the motor.

c) On all samples a lead distance of wire has to be allowed for before test measurements can be carried out. This lead is determined by the operating speed of the motor.

The advantages were deemed to outweigh the disadvantages. An example of how the disadvantages were overcome is as follows:- When an experiment was being carried out, the motor speed was monitored . This meant that the motor was quite free to find its load speed operating point without affecting the experiment.

The maximum load criterion was taken from previous research in this area carried out by Parvinmehr (19) and Crampton (11). The motor sizing was carried out on the assumption that the maximum drawing load of 500 N was required at low drawing speeds and a gearbox with a 10:1 gear ratio would be used. This case of the maximum drawing load was to occur at drawing speeds of 4 m/s or less. Hence the sizing of the motor and variac were as follows :-

$$\text{Motor Power} = \text{Force} * \text{Velocity}$$
$$= 500 * 4$$
$$= 2 \text{ kW}$$

To allow a 50 % factor of safety the motor chosen was a Newman 3kW, 4 Pole motor and the associated variac was a KEB Combivert 56. With this system a maximum theoretical load of 150 N could be drawn at a speed of 20 m/s, not allowing for resistances due to friction.

2.2.2. The Gearbox

The gearbox chosen was a David Brown CA237 10:1 Handling L Position gearbox with an exact gear ratio of 9.67:1. Its maximum input power rating at 1450 RPM was 2.55 kW. According to the manufacturers literature, this rating could be exceeded by 100 % on occasions without damaging the gearbox. However it was not expected to need to transmit power greater than the nominal rating of the gearbox very often.

2.2.3 The Bull Block

The bull block was originally designed with the same idea as the bull block used by Crampton [11] and Parvinmehr [13]. An assembly drawing of the bull block can be seen in Dwg. No. 104, Fig.8. Associated calculations for the loads on the bolts and whether the shaft would reach its whirling speed were made and are shown in Appendix A. The bearings used were SKF pillow block bearings (No. SY30TF) with a maximum operating speed of 4000 RPM. These bearings were chosen because they allowed a certain amount of play in the bearing alignment. The shaft was held in the bearing housing using grub screws.

Problems started to arise in this design during manufacturing. It was noted that when the parts in Dwg. No. 57 were welded onto the shaft (Dwg. No. 58,Fig. 9), the inner circle of holes (M6) could not accommodate the socket head cap screws (SHCS). It was decided at this point to ignore parts in Dwg. Nos. 55 and 54, Fig.10 and instead weld the part in Dwg. No. 53a,Fig. 11 to Dwg. No.57,Fig. 9. The small bull block in Dwg. No. 53a,Fig.11 was designed to replace the parts in Dwg. No. 53,Fig. 12. The small bull block (Dwg. No. 53a,Fig. 11) was first clocked up before being welded. The second part (Dwg. NO. 57,Fig. 9) was then mounted on the shaft and welded to the parts indicated by Dwg. Nos. 58,Fig. 9

and Dwg. No. 53a,Fig.11 but not matched with the similar part at the other end of the shaft. Consequently the bull block shell holders, Dwg. No.55,Fig. 13, were not symmetrically mounted as per design. The four of these shell holders (Dwg. No.55,Fig. 10) were then mounted onto the holder supports (Dwg. No.57,Fig. 9) and holes for the large bull block shells (Dwg. No. 56,Fig. 13) were drilled insitu and mounted. During commissioning it was noted that the shell holders (Dwg. No.57,Fig. 9) at either end of the shaft were running up to 0.5 mm out of centre; hence the grub screws were added to the large bull block shells (Dwg. No. 56,Fig. 13) to compensate for this. These added grub screws are not shown in Dwg. No. 56,Fig. 13.

The large bull block shells (Dwg. No. 56,Fig. 13) were made out of two sections of gun barrell piping. When the piping was split, sections were taken so that they would match up when mounted on the bull block holders. The idea was that the two half shells would be mounted onto the bull block holders with SHCS. However the pipe had built-in residual stresses during manufacturing which were relieved when the pipe was split. This caused a problem when mounting the large bull block shells onto the shell holders as the bull block holders were splayed. The holes drilled in the bull block shell holders were of a fine tolerance and did not allow much play. Consequently when the grub screws were adjusted, there were stresses which affected the shape of the bull block. These stresses caused deformation in a circumferential direction which varied longitudinally along the bull block. The variation in deformation was because the bolts (6*M8) which held the bull block to the shell holders were not mounted symmetrically. This made it impossible for the bull block to be clocked up to any degree of accuracy. As a result of this the bull block was out of balance and could only run up to speeds of 1000 RPM before excessive vibration occurred.

Leading on from this the bull block was redesigned and an assembly view of it can be seen in Dwg. No. 104a.,Fig. 14. In order to use as little additional material as possible the parts indicated in Dwg. No. 57,Fig. 9 were modified to parts in Dwg.No. 57a,Fig. 15. The bull block holder parts (Dwg. No. 57a,Fig. 15) were machined to fit the large bull block (Dwg. No. 56a,Fig. 16) with the bull block holder near the key-way and in Dwg. No. 58b,Fig. 17, having a slightly smaller diameter so that the large bull block would only fit on one way.

The large bull block, when finished, could only slide-fit on from the end of the shaft (Dwg. No. 58b,Fig. 17); the end which had the key-way. The original plan was to have the bull block slide over the bull block shell holders (see Dwg. No. 58b,Fig. 17), but in actual practice, during manufacture, this did not happen. Consequently the time required to remove the large bull block is about 30 minutes instead of 15 minutes because a connecting coupling (RM12) needs to be removed and replaced. Finally the outside of the bull block (Dwg. No. 56a,Fig. 16) was machined down to its external dimensions when fitted to the rest of the bull block assembly.

The bull block design allowed it to reach the maximum speed at which the motor could drive it, 2550 RPM. This gave the bull block a peripheral velocity of just over 20 m/s.

2.2.4 Overview Of The Drive Train

The various parts of the drive train were connected together using Fenner RM12 rigid couplings. The two drive configurations, motor/gearbox/bull block, can be seen in Dwg. Nos. 105,Fig. 18 and Dwg. No. 106,Fig. 19. The base plate dimensions for the drive train can be seen in Dwg. No. 68,Fig. 20.

When organising the elevations for the motor/gearbox configuration , it was decided that the motor would be on the base plate, made up of a number of strips of mild steel welded together. When the motor drove the bull block through the gearbox, the gearbox was mounted on two spacers as per Dwg. No. 73,Fig. 21 and the bull block rested on two spacers as per Dwg. No. 72,Fig. 21. During high speed drawing, ie. motor/bull block, the bull block was mounted on two spacers as shown in Dwg. No. 711,Fig. 21. These basic configurations can be seen in Photo 1 and Photo 2. In these photos one can see the locations of the fan used to cool the motor when running at low operating speeds. Photo 1 also has the large bull block standing up on end. Photo 2 shows that the gearbox does not need to be moved in order to run the motor/bull block configuration. The motor speed was determined using a remote sensing tachometer, Shimpo DT205, which recorded rotating motion of the motor's coupling by means of a piece of reflective tape. It had a recording time of about 3 seconds. From this rotary measurement one could determine the rotary speed of the bull block and hence its drawing speed.

The bull block's operating range of drawing speeds is shown below :-

	Min. Speed (m/s)	Max. Speed (m/s)
Motor/Gearbox/Small Bull Block	0.03	0.81
Motor/Gearbox/Large Bull block	0.08	2.00
Motor/Small Bull Block	0.3	8.00
Motor/Large Bull Block	0.8	20.0

With these configurations it is possible to get the whole speed range for the bull block with good over-lap between configurations. The only draw-back with this drive train design at present is that when operating with the bull block and motor configuration, it is only lined up for one experiment. This could be amended, though, with minimum alterations to the base plate so that the motor with the bull block could draw the wire along the length axis of the table. This needs to be incorporated into a future design.

2.3 Design of The Wire Feed Mechanism.

The initial wire concept was that it had a diameter in the range of 0.1 to 1 mm. It was on this basis that a rotary wire feed mechanism was designed. This consisted of a wire feed mechanism (Dwg. No. 102,Fig. 22 and a pulley mechanism (Dwg. No. 103,Fig. 23. The pulley was used to align the wire with the pressure die chamber. An overall view of their locations on the drawing bench can be seen in Dwg. No. 105,Fig. 18 and Dwg. No. 106,Fig. 19. This design looked promising until load tests were carried out on the 0.03 mm diameter wire. The tests were carried out using 10 strands of wire linked in parallel. The test showed that the wire had a breaking load of 0.4N. The calculations shown in Appendix B were carried out and an estimate of the maximum drawing speed was calculated, taking into account perfectly balanced equipment and viscous losses. An estimate of 1.5 m/s was calculated. When this was tested on the drawing bench it was found that the wire could only be pulled at 0.12 m/s before breaking. On hindsight the resistive value of the bearings lubricant was given too low an estimate for viscosity. Also the pulley was assumed to be perfectly balanced, which in fact was not so.

A much simpler and more experimental design was then developed. It involved pulling the wire off the reel along its longitudinal axis. This was experimentally shown to be satisfactory and modifications to the design were made. The overall design can be seen in Dwg. No. 107,Fig. 24. When tested to see how fast the 0.03 mm wire could be unwound from the spool, it was found that it could unwind at speeds of up to at least 10 m/s. At this point it was decided that tests would not reach speeds faster than this so the design was deemed to be satisfactory.

2.4 Design Of The Pressure Die Chamber.

The pressure die chamber was designed along similar lines to that of Crampton's and Parvinmehrs's apparatus, except, the wire was to be drawn in a vertical direction. This removed the need for a seal at the entrance to the melt chamber. The pressure die chamber was to be capable of being heated to 400 ^{o}C. using heater bands. The heater bands chosen were IHNE-TESCH high capacity ceramic insulated cylindrical heater bands with an internal diameter of 80 mm by 36 mm high. There were two of them; one for the pressure die chamber and one for the melt chamber. Since the pressure die chamber and melt chamber were to be capable of heating up to temperatures of 400 ^{o}C it was decided to have an insulated housing surrounding the apparatus. This housing was designed to be filled with Pilkingtons rocksil bat so that the outside surface would not be at temperatures above about 60 ^{o}C. Heat loss calculations can be seen in Appendix C. When the unit was tested out at 400 ^{o}C it was found that most heat was transfered through the bars supporting the pressure unit and so the insulation was ignored. There were also sizable convection currents which carried the heat away. Due to these convection currents the temperature of the insulation housing was not sufficiently high to receive a serious burn if touched for a fraction of a second.

The original layout of the pressure unit can be seen in Dwg. No. 100,Fig. 25 and Dwg. No. 101,Fig. 26 along with its associated parts. It was designed so that one could gain easy access to the pressure die unit without having to dismantle the whole unit.

The path of the wire through the pressure assembly was as follows. It entered the melt chamber through a cover which was used to prevent heat escaping from the chamber. The melt chamber was designed to hold 2*E5 mm^3 of molton polymer which could coat 115 km of wire with a nominal-cross sectional diameter of 0.03 mm^2 and a coating thickness of 7.5 μm. From the melt chamber it passed through a 2mm bore passage (Dwg. No. 50a,Fig. 27) which, if necessary, could allow multiple strands of fine wire to pass through the bore passage. From here the wire passes through an insert (Dwg. 67 assembly,Fig. 28). The insert housing allows inserts to be located within the housing. The holes in the inserts will be used to test the variations in the coating thickness of the wire. The wire then passed through a die (if present) and through a holding plate (Dwg. No. 51,Fig. 29) and subsequently to the bull block. In essence this was the original design.

There were problems in manufacturing the small bored holes for the die inserts (see Dwg. No. 672,Fig. 30). It was found virtually impossible to drill the holes using mechanical engineering workshop facilities. The holes were subsequently drilled by laser. A laser was used to cut through 3 times the thickness of metal that could have possibly been drilled with an ordinary drill bit. The thickness of the part in Dwg. No. 672,Fig.30 was chosen because of the flute length of the 0.25 mm. drill bit.

2.4.1 Modifications To The Pressure Chamber Design

During manufacturing it was decided that the insulation housing design could be greatly simplified. This was done by eliminating parts in Dwg. Nos. 59,60,62,63 and 65,Figs. 31,32,33 and replacing them with two parts as seen in Dwg. No. 59a,Fig. 34 and Dwg. No.60,Fig. 35. Both these parts were simpler to make and allowed easier access to the pressure chamber than the original design. The access was so easy that within 3 minutes one could have the melt chamber removed from the pressure chamber and gain access to the pressure chamber,

The second modification came about as a result of experimentation. It was noted that the 2mm bored chamber provided a resistance for the wire passing through the melt chamber but would not appreciably increase the wire coating thickness. Also, when the heater bands were set to a temperature of , say 280 ^{o}C, the temperature where the die was located (Dwg. No. 100,Fig. 25) was only about 250 ^{o}C; that is 30 ^{o}C below the set temperature. On this basis it was decided to modify the design of the pressure die chamber to that seen in Dwg. No. 50b,Fig. 36 and modify the inserts to those seen in Dwg. No. 71b,71c, and 71d,Figs. 37,38.

The parts in Dwg. No. 71c and 71d,Fig. 38 were made on a lathe. The reasoning behind using these small discs was that only a small resistance force was required for the coating of wire and that extremely high pressures were not being developed. The discs were made out of mild steel but would be made out of tool steel and drilled with a laser if used in industry. However, for experimental purposes mild steel provided sufficient wear resistance.

Photos 3 and 4 show general views of the wire feed mechanism and pressure chamber. The wire feed mechanism contains a spool of wire which is 0.03 mm in diameter.

2.5 Design Of The Electrical Installation.

The electrical installation basically is divided into two areas :-

1)The electrics for the motor.

2) The electrics for the heater bands.

The bench was to be connected by a 3 phase plug to the mains and all electricals on the bench were isolated from the outside by means of a 3 phase isolating switch and a fuse box. From the fuse box electricity was fed to motor controller, heater bands and associated controllers.

2.5.1 The Motor's Electrical Wiring Arrangement.

From the fuse box the 3 phases were brought to the KEB Combivert 56 frequency inverter. The 3 kW motor was then connected from this inverter by means of shielded cable. The frequency inverter has a number of facilities which allows one to vary the operating parameters of the motor; these include being able to adjust the minimum/maximum speed of the motor, its acceleration/deceleration times along with being able to increase the maximum torque of the motor above its design torque for short periods of time. It also provided fail safes for the motor so that if the motor overheats or a phase fails, the inverter will shut the motor down.

The frequency inverter was normally operated from the remote control unit which was mounted on the bench (see Photo 5). From this remote control unit one could run the motor forward or reverse, start or stop the motor, adjust the speed of the motor and also read the frequency at which the motor was being run-at. Also in Photo 5 the Shimpo DT205 remote tachometer is shown.

One of the phases on the bench was used for a bank of single phase plugs. One of these plugs was used for the fan which provided extra cooling for the electric motor when running at low speeds.

2.5.2 Heating Band Wiring Configuration Design

Originally the drawing bench was concieved as having two heater bands and associated PID controllers with iron constant thermocouples (Type J). A secondary measurement device was proposed and purchased for verification of temperatures using a digital readout with a type K thermocouple sensor. A 12-way selector switch was proposed so that all the heater bands could be monitored at once. This selector switch was then to be connected to the digital readout.

After discussions the basic heater band control system was made a good deal more versatile. It was to control up to 12 heater bands, controlling up to 6 heater bands at any one time. The original two heater controllers were West 3300 PID controllers. With these controllers it was possible to adjust the proportional, integral and differentiol control; to set the maximum control temperature and also the period of sensing; and to set the maximum time that power could be supplied to the heater band relay in percentage terms. The heater bands were controlled using a relay switch which was activated by the controllers. With these controllers it was possible to tune each required heater band system so that the temperature fluctuated no more than $\pm 1\ ^{o}C$ around the set point.

To facilitate the operation of 6 heater bands simultaneously, it was decided to purchase 4 Sensor D type PID controllers. These controllers did not prove quite as accurate as the West 3300 as they could only obtain an accuracy of $\pm$ 3 ^{o}C. with tuning.

Each controller operated a relay switch which in turn powered a heater band. The temperature of the heater bands was then monitored by the controller through a thermocouple (Type J). All 6 controllers were powered from a single phase of the bench's supply but in order to try to keep a balanced load on the phases it was decided that each phase would supply two of the relays for the heater bands. Shielded cable was used for the power cable to the heater bands. The power and thermocouple cables were aligned so that they would not run along the same path.

In order to ensure the safe operation of the heater bands it was decided to interlock the heater band power supply and thermocouple sensors together when being connected to the controllers. In this way it would be possible to operate one set of 6 heater bands safely and then the other set of 6 heater bands safely. A final view of the installation can be seen in Photo 6. Each heater band was connected to the relay power supply by means of a 3-pin plug. In the end configuration each heater band plug and its associated socket which led to the controller were labelled so as to prevent wrong connection. The plug and socket system is the weak link in the interlock system.

(See Appendix F for block diagram of electricals.)

2.6 Design Of The Load Measuring Device

The load measuring facility was designed to be mounted between the drawing block stand (Dwg. No. 71,Fig. 39) and the pressure die chamber (see Dwg. No. 100,Fig. 25). In order to achieve the design criterion of only having linear motion in the vertical plane, a box design was chosen (Dwg. No. 64,Fig. 33). The assumptions in this design are as follows :-

1) The corners of the bracket act as if they are built in beams (not an exact property, but nearly so). This implies there is zero slope at each corner.

2) As the bracket is symmetrical, a vertically applied load will not produce noticable angular deflection.

3) Tensile and compressive stresses in the members can be ignored as they are minimal compared to the peripheral stress on the members' extreme edges caused by the vertical load.

Following on from these assumptions, the behaviour of the load measuring facility can be seen in Fig. 40.

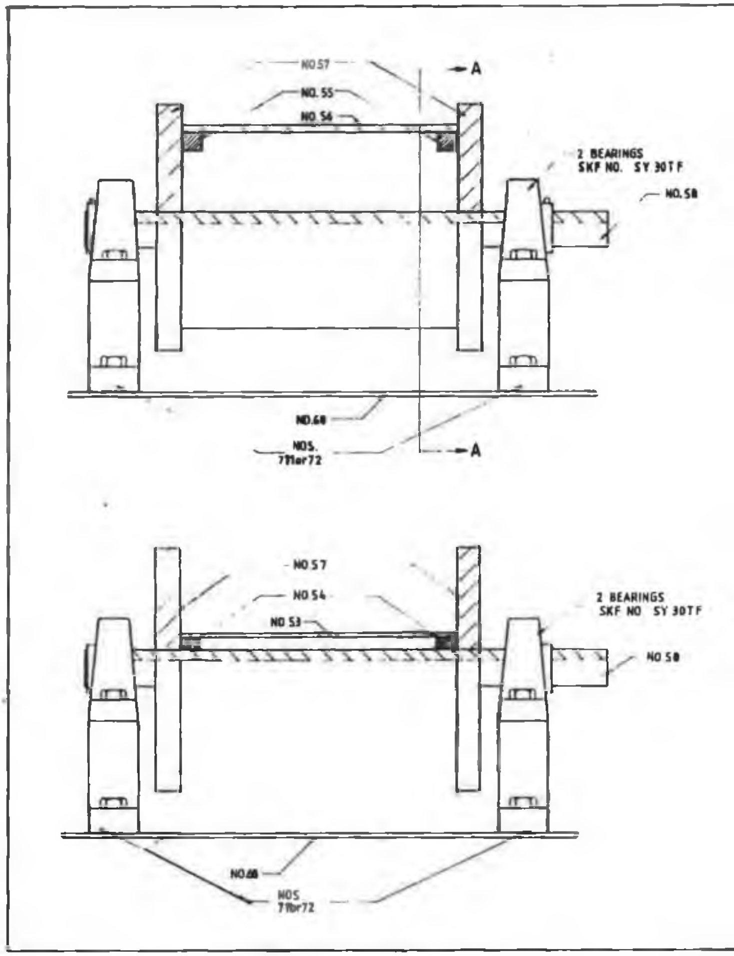
In this figure (exaggerated) destinctive hogging and sagging characteristics of the load measuring device are observed. At the point where sagging becomes hogging there is no moment transmitted and the members are in complete shear. For calculating the maximum load it was assumed that the load is to be applied at this point. Since there are two members, the applied load is to be applied equally over the two beams. The method used for calculating the maximum applied load can be seen in Appendix D. The maximum design load which could be applied to the load measuring device was found to be about 450 N. This included the load applied by the pressure die unit. The strain on the members was to be measured using two strain gauges as shown in Fig. 40. These gauges were connected in a half-bridge configuration and then connected to a Fylde 254-GA strain gauge amplifier by means of shielded cable. The output from the amplifier was then fed to a Linseis L6514-4 chart recorder for the output.

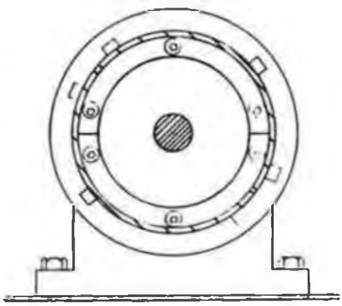
This apparatus was not used when carrying out experiments with the drawing of wire because of the low forces created by coating of the fine wire. It was, however tested, and could give a distinctive reading for an applied load of 100 N. It had a good deal of interference but this was probably due to not having resistors with a low tolerance in the wheatstone bridge or bad connections which would cause interference. Some of this interference could be filtered out after the pre-amplifier with the use of an integrator. The system may require further modifications in the future.

2.7 Design Of The Drawing Bench

The drawing bench frame size was chosen in order to facilitate the drawing of wire from more than one experimental source with as little modification as possible. Its basic structure was made out of 50*50*2 mm box section with structural supports as seen in Dwg. No. 66,Fig. 41. To this was added the electrical equipment, a plate for the drive train assembly (Dwg. No. 68,Fig. 20) and a plate for mounting of experiments (Dwg. No. 69,Fig. 42). In the final design the steel plate (Dwg. No. 70,Fig. 18,19) was ignored and incorporated into the steel plate Dwg. No. 69,Fig. 42. The support stand (Dwg. No. 71,Fig. 39) was used as a support for the pressure die chamber, load cell and wire feed mechanism for the experiments reported in this thesis. This stand can be attached to the plate (Dwg. No. 69,Fig. 42) in up to 4 positions so that the pressure die chamber would always be in a vertical line with the drawing surface of the bull block in its 4 possible bull block sizes and locations.

The overall view of the drawing bench can be seen in Photo 7. This shows all the equipment which was designed for this work plus another individual's experiment mounted on the drawing bench. An overview of the bench can also be seen in Dwg. Nos. 105,Fig. 18 and Dwg. No. 106,Fig. 19 with the original design for the wire feed mechanism. A list of the materials used on the drawing bench can be seen in Materials Table 1.

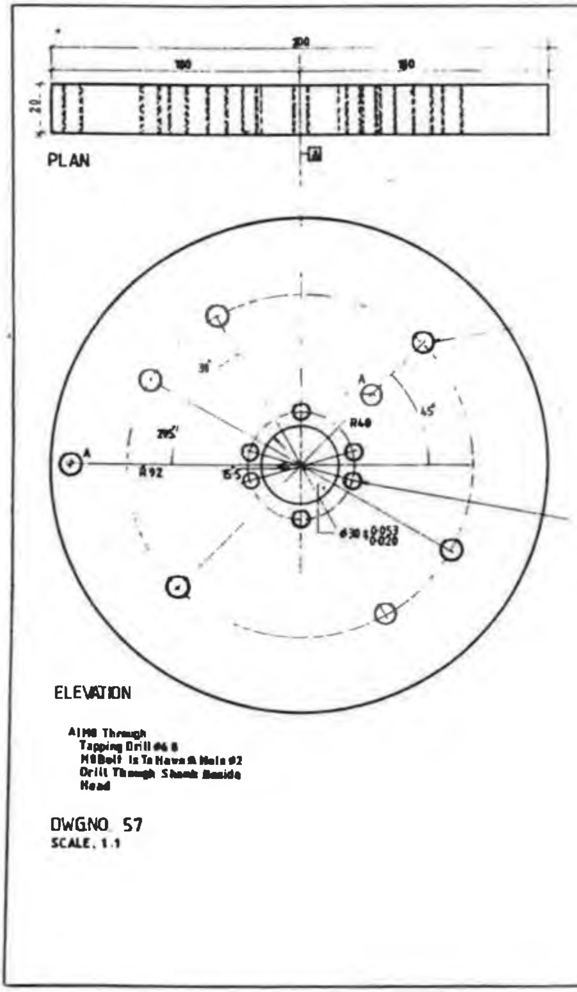

NO 57
NO. 55
NO. 56
A
2 BEARINGS
SKF NO. SY 30TF
NO. 58
NO.68
NOS.
71or72
A
NO 57
NO 54
NO 53
2 BEARINGS
SKF NO SY 30TF
NO 58
NO.68
NOS
71or72



SECTION A-A

FIG. 8

DWG BY:- Roger Lamb
TITLE:- PULLEY BLOCK ASSEMBLY
DWG. NO:-104
SCALE:- 1:2
SCHOOL OF MECHANICAL ENGINEERING
MATERIAL :- SEE DWGS
DATE 13/5/86


200
100
100
20
PLAN
A
R40
R92
30°
45°
ELEVATION
A) M8 Through
Tapping Drill Ø6.8
M8 Bolt Is To Have A Hole Ø2
Drill Through Shank Beside
Head
DWG NO 57
SCALE. 1:1

6 Holes M8 Through On PCD 131

Tapping Drill ⌀6·8

6 Holes M6 Through On PCD 43

Tapping Drill ⌀5

NOTE:- Chamfer External Edges 1 x 45°

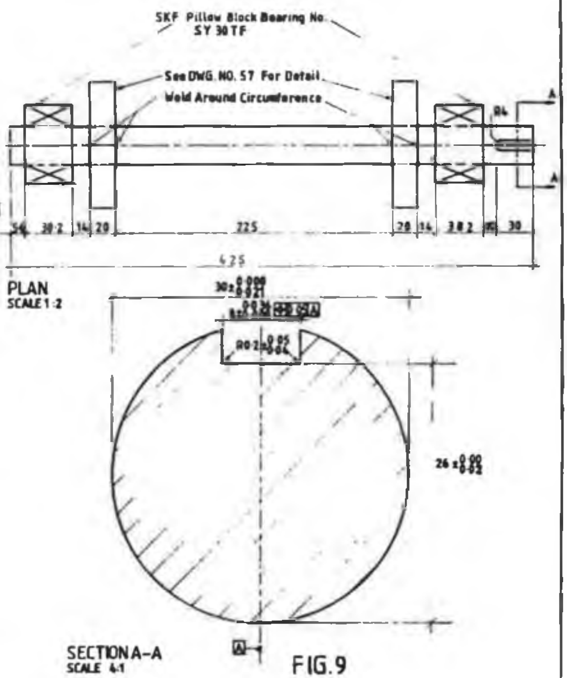
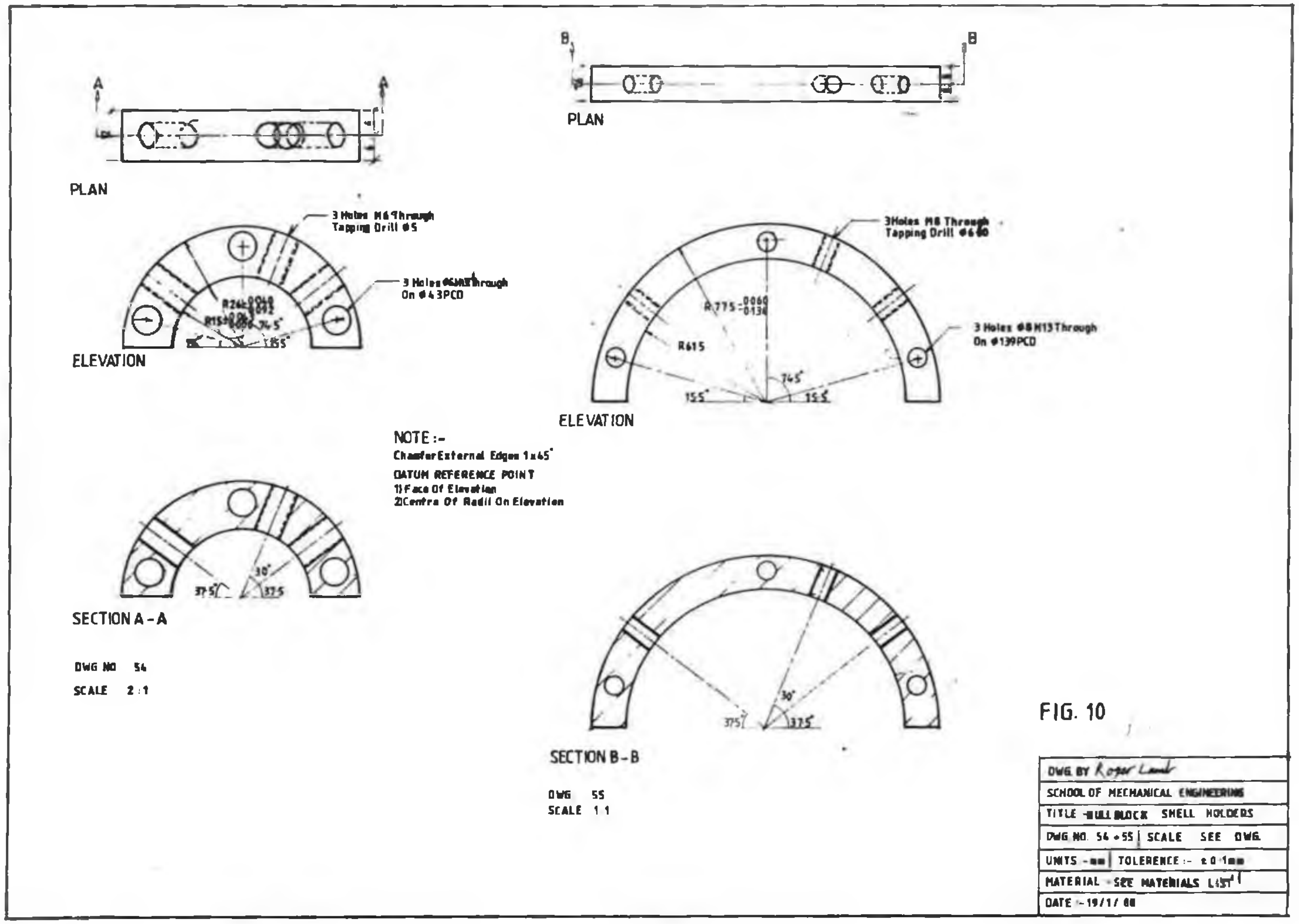
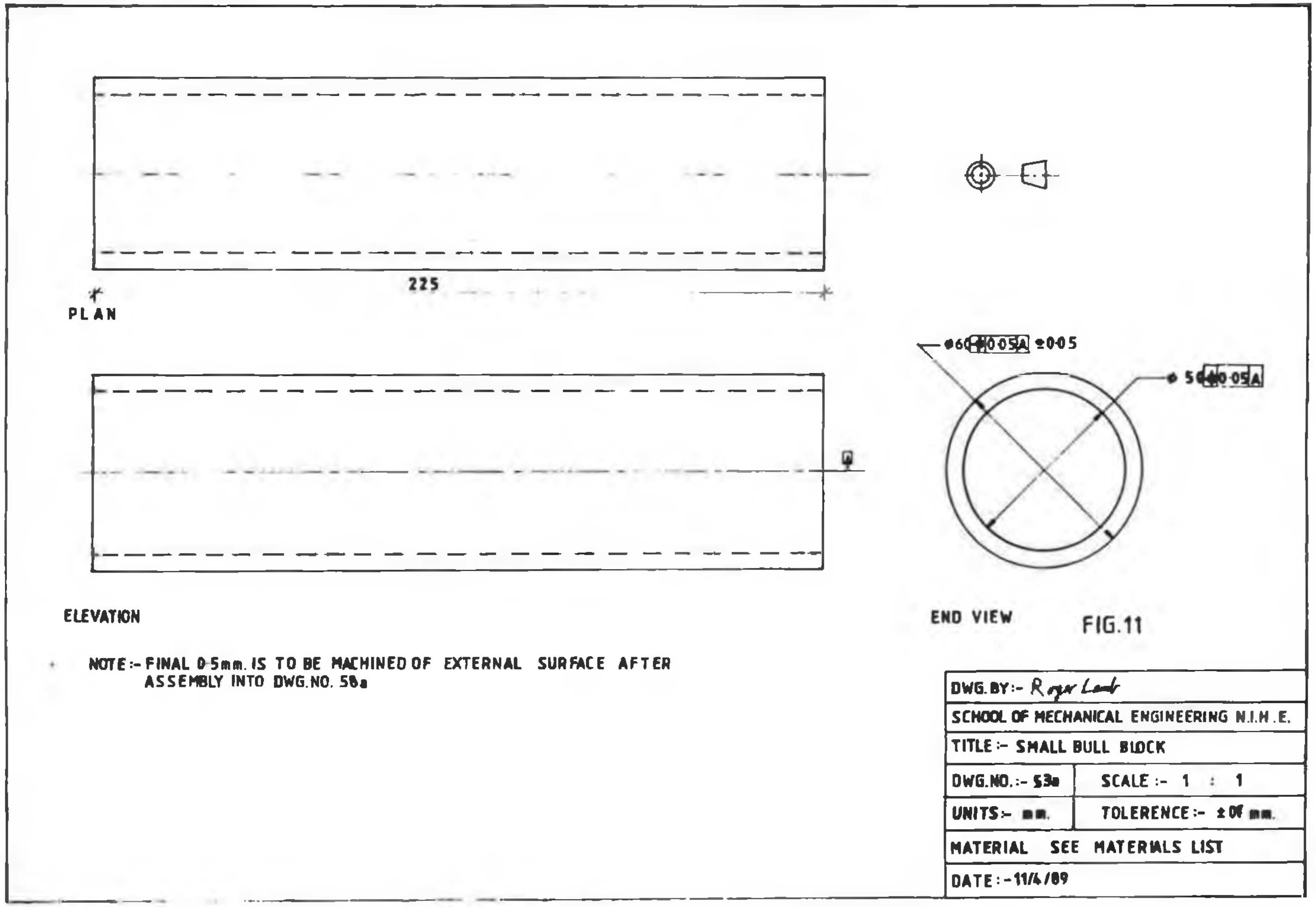


FIG. 9

DWG 58

DWG. BY	
SCHOOL OF MECHANICAL ENGINEERING	
TITLE :- HOLDER SUPPORT + SHAFT	
DWG. NO. 57 + 58	SCALE SEE DWG.
UNITS :- mm	TOLERENCE ± ·01 mm
MATERIAL - SEE MATERIALS LIST.	
DATE :- 1/2/88	


PLAN
ELEVATION
SECTION A - A
DWG NO 54
SCALE 2:1
PLAN
ELEVATION
SECTION B - B
DWG 55
SCALE 1:1
NOTE :-
Chamfer External Edges 1x45°
DATUM REFERENCE POINT
1) Face Of Elevation
2) Centre Of Radii On Elevation
3 Holes M6 Through
Tapping Drill ø5
On ø43PCD
3Holes M8 Through
3 Holes ø8H13 Through
On ø139PCD
R615
7·5°
15·5°
30°
37·5°
DWG BY Roger Lamb
SCHOOL OF MECHANICAL ENGINEERING
TITLE - BULL BLOCK SHELL HOLDERS
DWG NO. 54 + 55 | SCALE SEE DWG.
UNITS - mm | TOLERENCE :- ± 0·1mm
MATERIAL - SEE MATERIALS LIST
DATE :- 19/1/88
FIG. 10



225
PLAN
ELEVATION
ø60 ±0·05
ø 56
0·05 A
END VIEW
NOTE :- FINAL 0·5mm. IS TO BE MACHINED OF EXTERNAL SURFACE AFTER ASSEMBLY INTO DWG.NO. 58a
DWG.BY:- Roger Lamb
SCHOOL OF MECHANICAL ENGINEERING N.I.H.E.
TITLE :- SMALL BULL BLOCK
DWG.NO. :- 53a
SCALE :- 1 : 1
UNITS :- mm.
TOLERENCE :- mm.
MATERIAL SEE MATERIALS LIST
DATE :- 11/4/89

FIG.11

NOTE:-
DATUM REFERENCE POINTS
1) Lower Surface Elevation
2) Edge (Left) On Plan
3) Focus Of Radii On End View
Chamfer Edges 1x45°

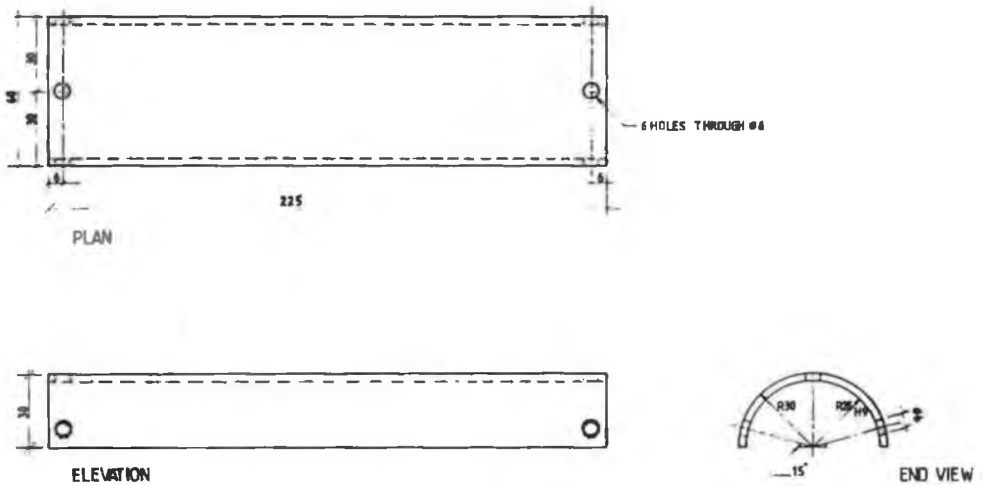
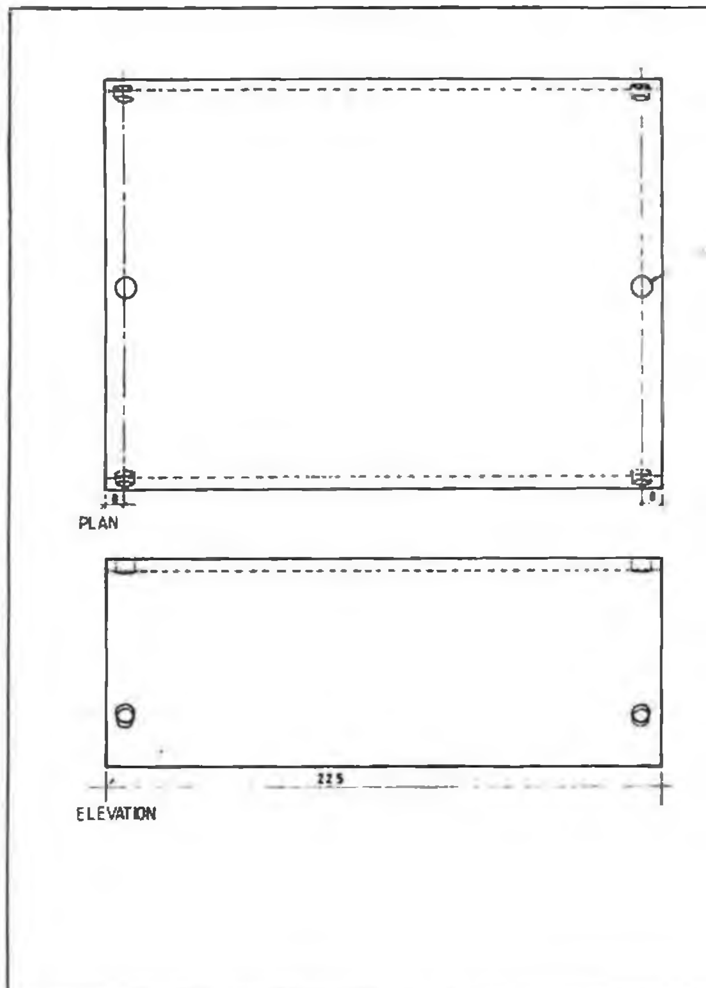


FIG. 12

QUANTITY:- 2	DATE 2/12/87
MATERIAL:- SEE MATERIALS LIST	
UNITS:- mm	TOLERANCE ±0·1 m
TITLE:- Small Dug Shell	
DWG. NO. 53	SCALE 1:1
SCHOOL OF MECHANICAL ENGINEERING	
DWG BY	


PLAN
225
ELEVATION

NOTE :-

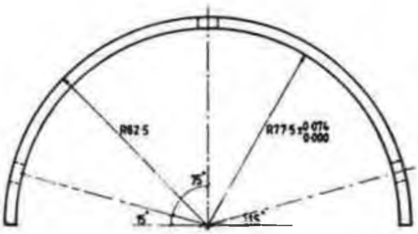
Chamfer External Edges 1 x 45°

DATUM REFERENCE POINT

1) Face Of End View

2) Centre Of Radii On end View

— 6 Holes Ø8H13 Through



END VIEW

FIG. 13

DWG BY *Roger Lamb*	
SCHOOL OF MECHANICAL ENGINEERING	
TITLE - LARGE BULL BLOCK SHELL	
DWG. NO 56	SCALE 1:1
UNITS :- mm	TOLERENCE ± 01 mm
MATERIAL :- SEE MATERIALS LIST	
DATE 21 / 1 /88	

NOTE:- DWG. NO. 59a HELD ONTO DWG. NO. 58a BY 6 SHCS, M10 x 25 LONG

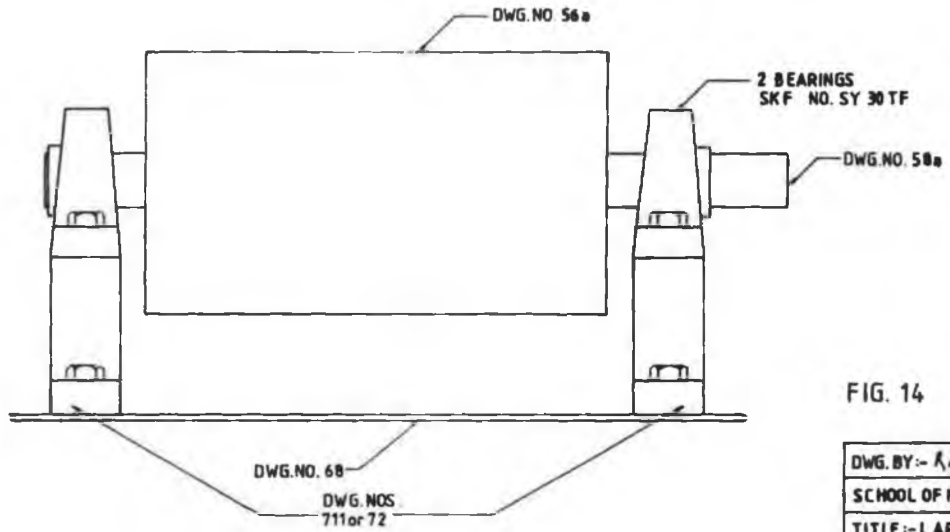


FIG. 14

DWG. BY:- [illegible]	
SCHOOL OF MECHANICAL ENGINEERING N.I.H.E.	
TITLE:- LARGE BULL BLOCK ASSEMBLY	
DWG. NO:- 104A	SCALE:- 1:2
UNITS:- mm	
MATERIAL:- SEE MATERIALS LIST	
DATE:- 14/4/89	

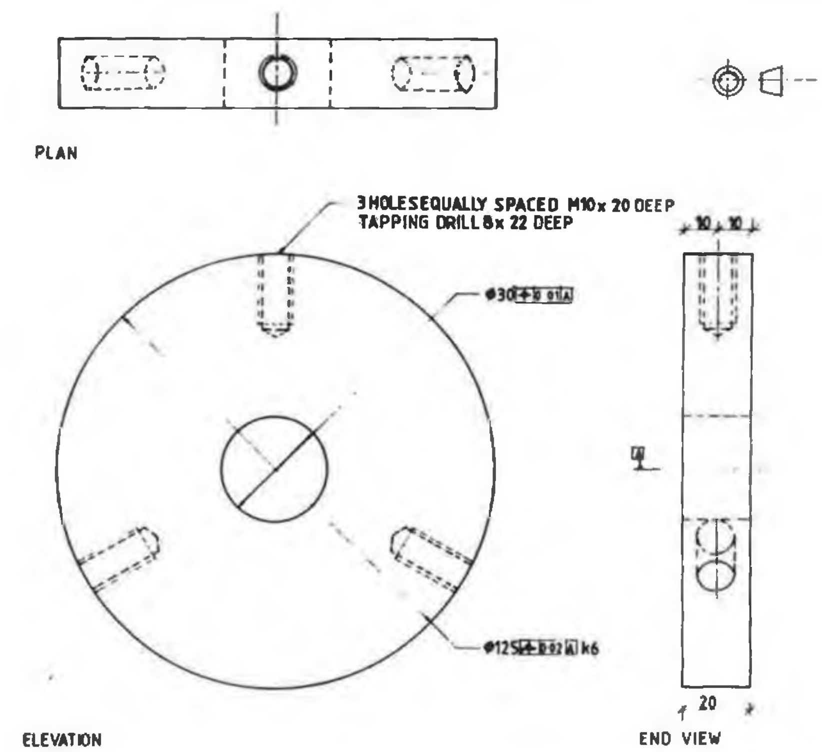
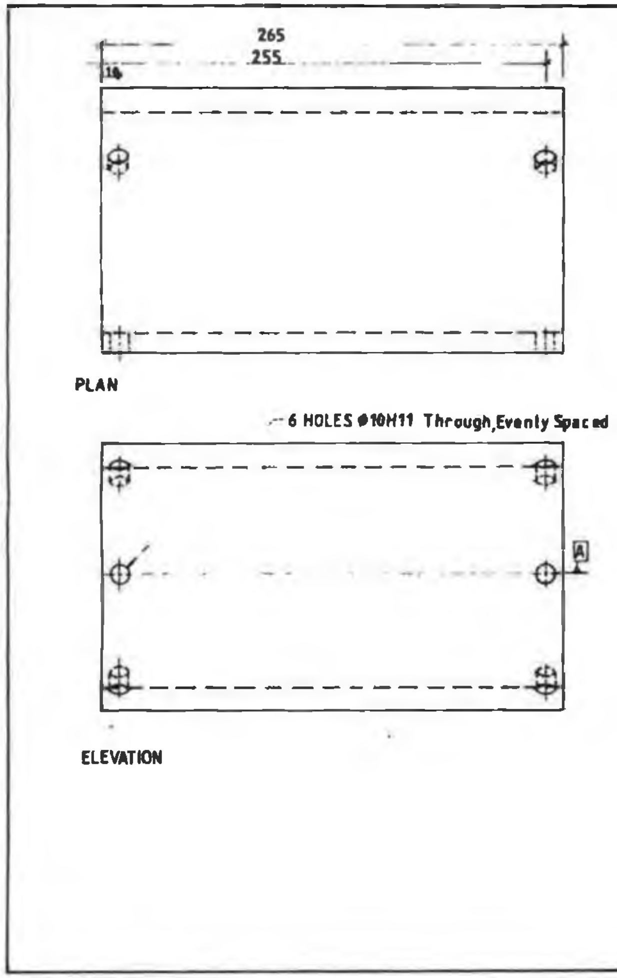


FIG. 15

DWG. BY:- Roger Lamb	
SCHOOL OF MECHANICAL ENGINEERING N.I.H.E.	
TITLE :- BULL BLOCK HOLDER	
DWG.NO. 57a	SCALE :- 1:1
UNITS :- mm	TOLERENCE :- ±0·1 mm
MATERIAL :- SEE MATERIALS LIST	
DATE :- 10/4/89	


265
255
10
PLAN
6 HOLES Ø10H11 Through, Evenly Spaced
A
ELEVATION

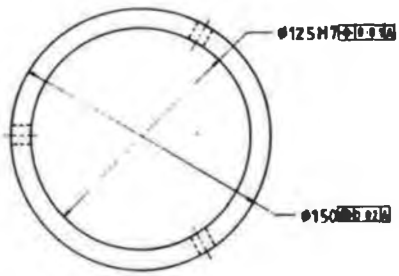
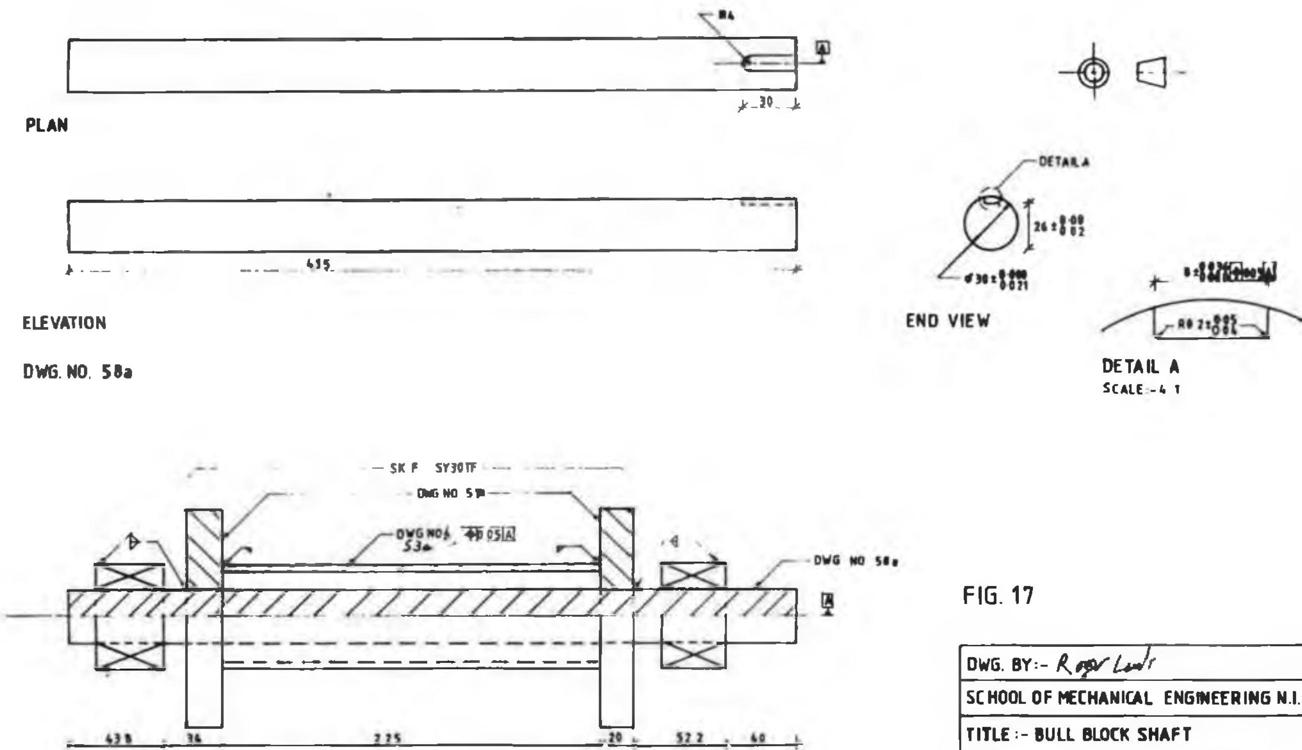


FIG. 16

END VIEW

DWG. BY:- Roger Lamb	
SCHOOL OF MECHANICAL ENGINEERING N.I.H.E.	
TITLE:-LARGE BULL BLOCK	
DWG. NO. 56a	SCALE 1 : 2
UNITS:- mm	TOLERENCE:- ±0·1 mm.
MATERIAL:- SEE MATERIALS LIST	
DATE.- 7/4/87	



DWG.NO.58b
TITLE:-SMALL BULL BLOCK ASSEMBLY

FIG. 17

DWG. BY:- Roger Lewis	
SCHOOL OF MECHANICAL ENGINEERING N.I.H.E.	
TITLE :- BULL BLOCK SHAFT	
DWG. NO.:- 58a,b	SCALE 1: 2
UNITS :- mm	TOLERENCE:- 0·1mm
MATERIAL:- SEE MATERIALS LIST	
DATE:- 11/4/89	

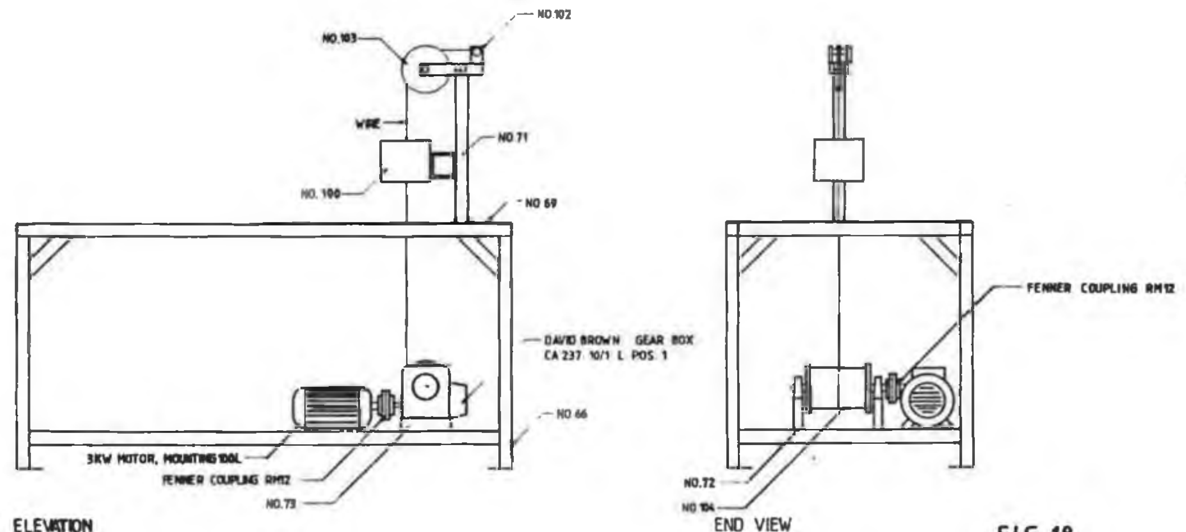


FIG. 18

DWG. BY:- Roger Lamb	
SCHOOL OF MECHANICAL ENGINEERING	
TITLE:- DWG. BENCH WITH GEAR BOX	
SCALE:- 1:10	
DWG. NO.:- 105	
MATERIAL:- SEE DWGS.	
DATE:- 16/5/88	

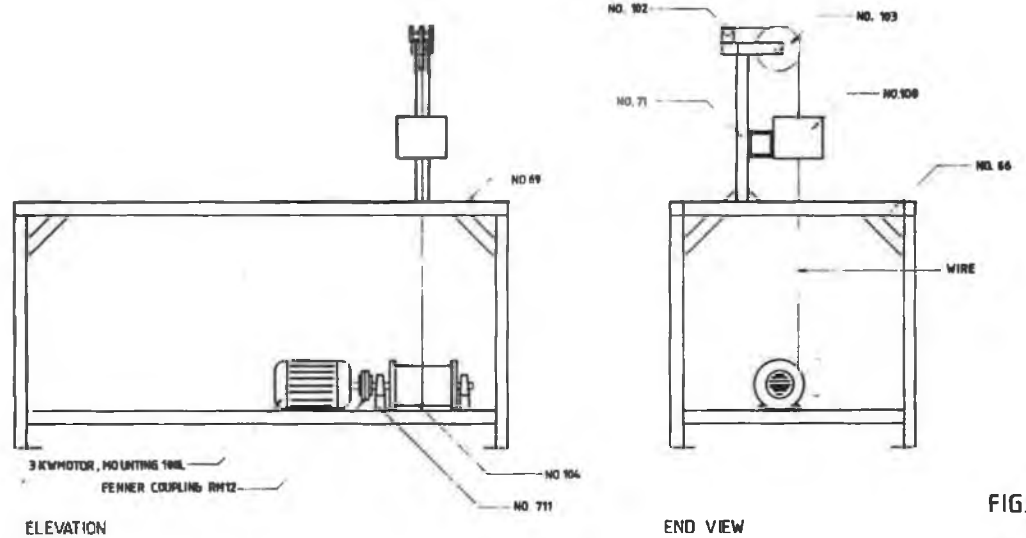


FIG. 19

DWG. BY:- Roger [illegible]
SCHOOL OF MECHANICAL ENGINEERING
TITLE:- DRAWING BENCH
DWG. NO:- 106
SCALE:- 1:10
MATERIAL:- SEE DWGS.
DATE - 17/5/8

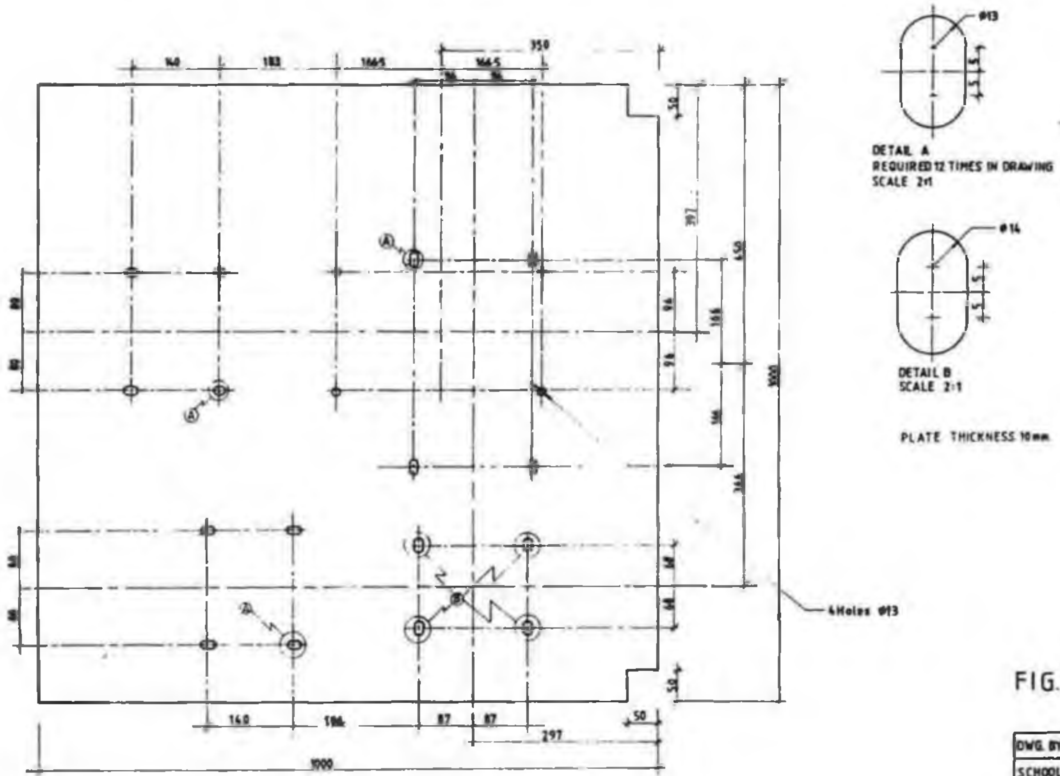
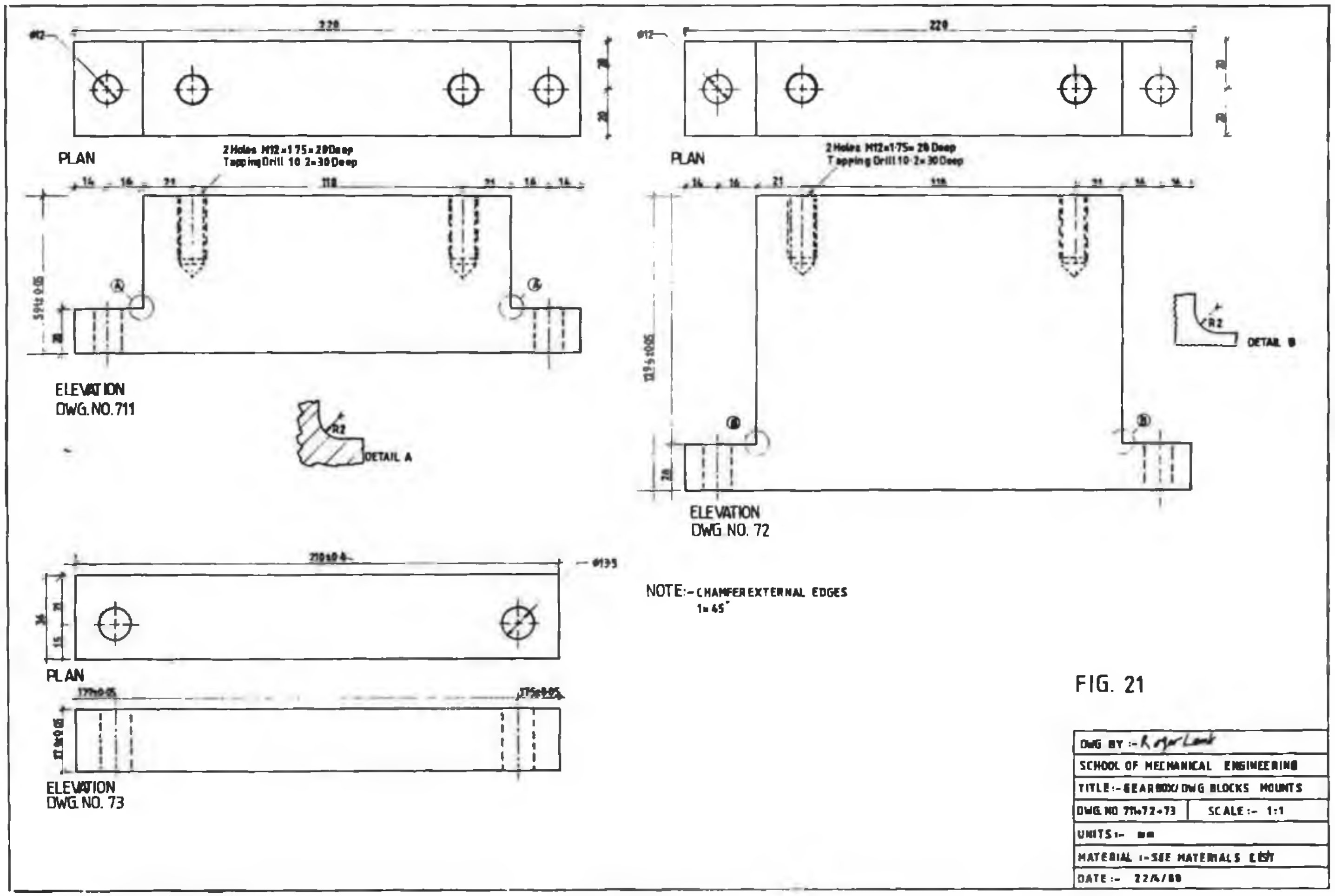
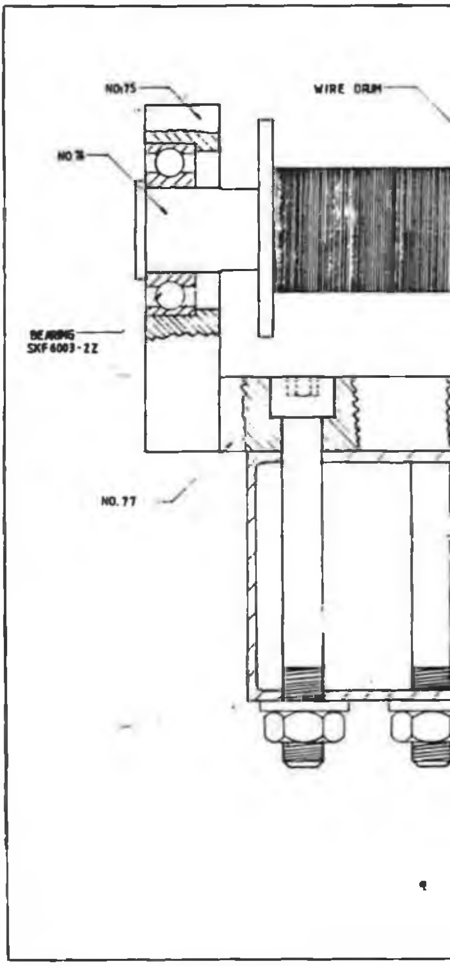


FIG. 20

DWG. BY :- Roger Lamb	
SCHOOL OF MECHANICAL ENGINEERING	
TITLE :- DRIVE TRAIN MOUNTING PLATE	
DWG. NO. :- 68	SCALE :- 1:4
UNITS :- mm	TOLORENCE :- ±0·5
MATERIAL :- SEE MATERIALS LIST	
DATE :- 10/5/88	


PLAN
2 Holes M12×1.75×20 Deep
Tapping Drill 10.2×30 Deep
ELEVATION
DWG. NO. 711
DETAIL A
R2
PLAN
ELEVATION
DWG. NO. 72
DETAIL B
PLAN
ELEVATION
DWG. NO. 73
NOTE:- CHAMFER EXTERNAL EDGES
1×45°
DWG BY :- Roger Lamb
SCHOOL OF MECHANICAL ENGINEERING
TITLE:- GEARBOX/DWG BLOCKS MOUNTS
DWG. NO 711+72+73
SCALE :- 1:1
UNITS :- mm
MATERIAL :- SEE MATERIALS LIST
DATE :- 22/6/88
FIG. 21


NO.75
WIRE DRUM
NO 74
BEARING
SKF 6003-ZZ
NO. 77

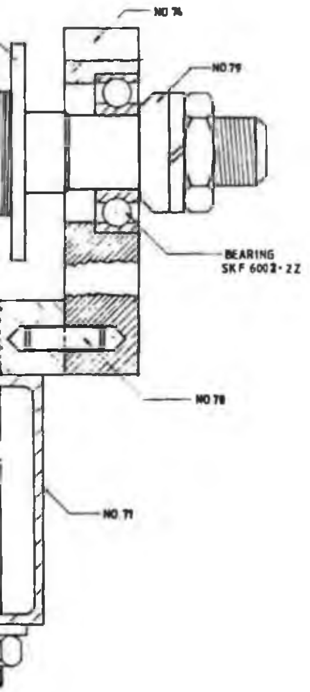
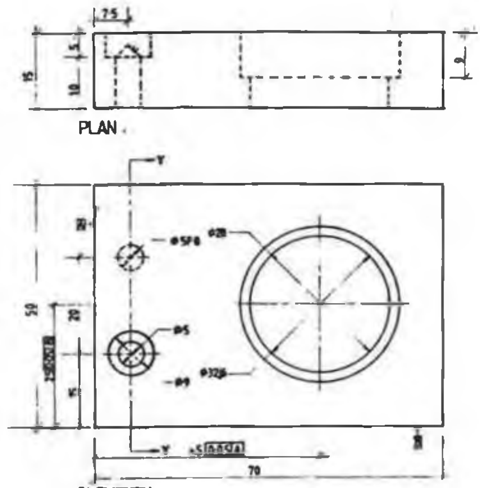


FIG. 22

DWG BY:- Roger Lamb	
SCHOOL OF MECHANICAL ENGINEERING	
TITLE:- WIRE REEL ASSEMBLY DWG.	
DWG NO.:-102	
SCALE:- 2:1	
MATERIAL:- SEE DWGS	
DATE:- 3/5/88	



DWG. NO. 74

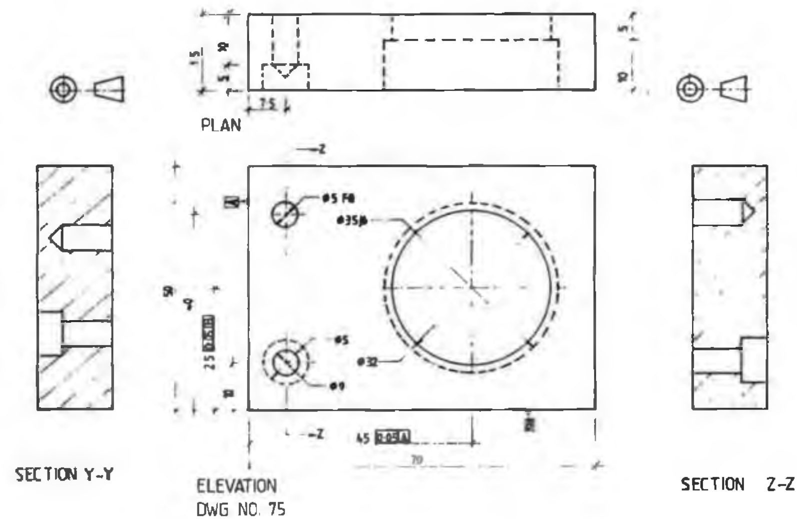


FIG. 22a

DWG BY:- [illegible]	
SCHOOL OF MECHANICAL ENGINEERING	
TITLE:- WIRE HOUSING SUPPORTS 1 & 2	
DWG NO. 74 + 75	SCALE 2:1
UNITS:- mm.	TOLORENCE:- ±0.1
MATERIAL:- SEE MATERIALS LIST	
DATE:- 2/5/88	

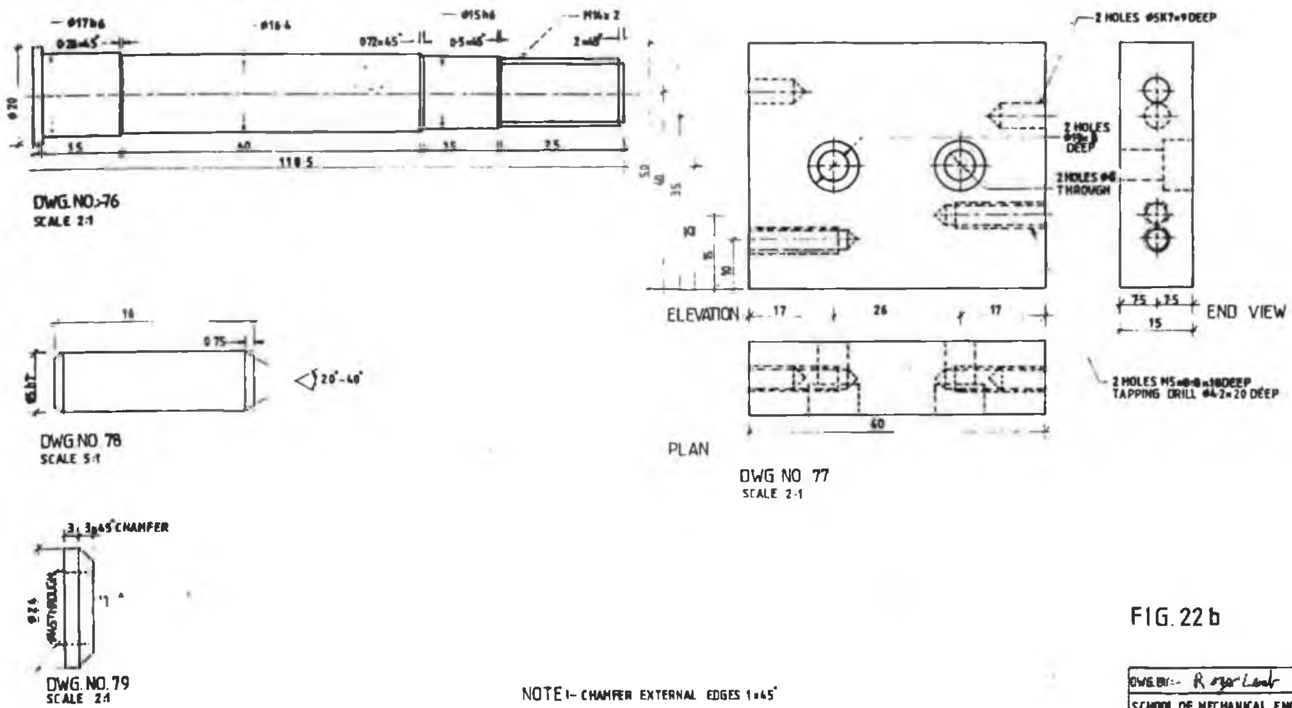


FIG. 22 b

DWG BY:- Roger Lamb
SCHOOL OF MECHANICAL ENGINEERING
TITLE:- WIRE HOUSING PARTS
DWG NOS.:-76 - 79 | SCALE :- SEE DWGS
UNITS:- mm. | TOLORENCE:± 0·01
MATERIAL:- SEE MATERIALS LIST
DATE:- 3/5/88

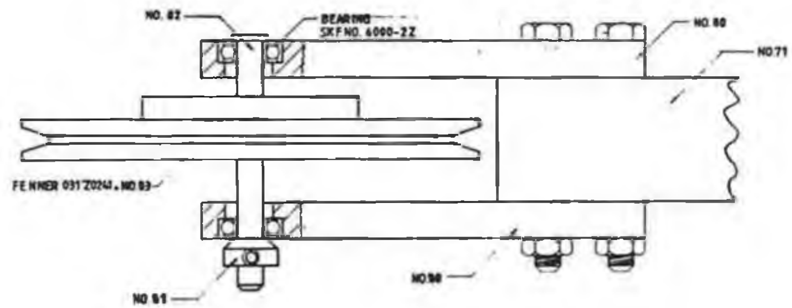


FIG. 23

DWG BY
SCHOOL OF MECHANICAL ENGINEERING
TITLE:-PULLEY ASSEMBLY
DWG NO:- 103
SCALE:- 1:1
MATERIAL:- SEE DWGS.
DATE:- 9/5/88

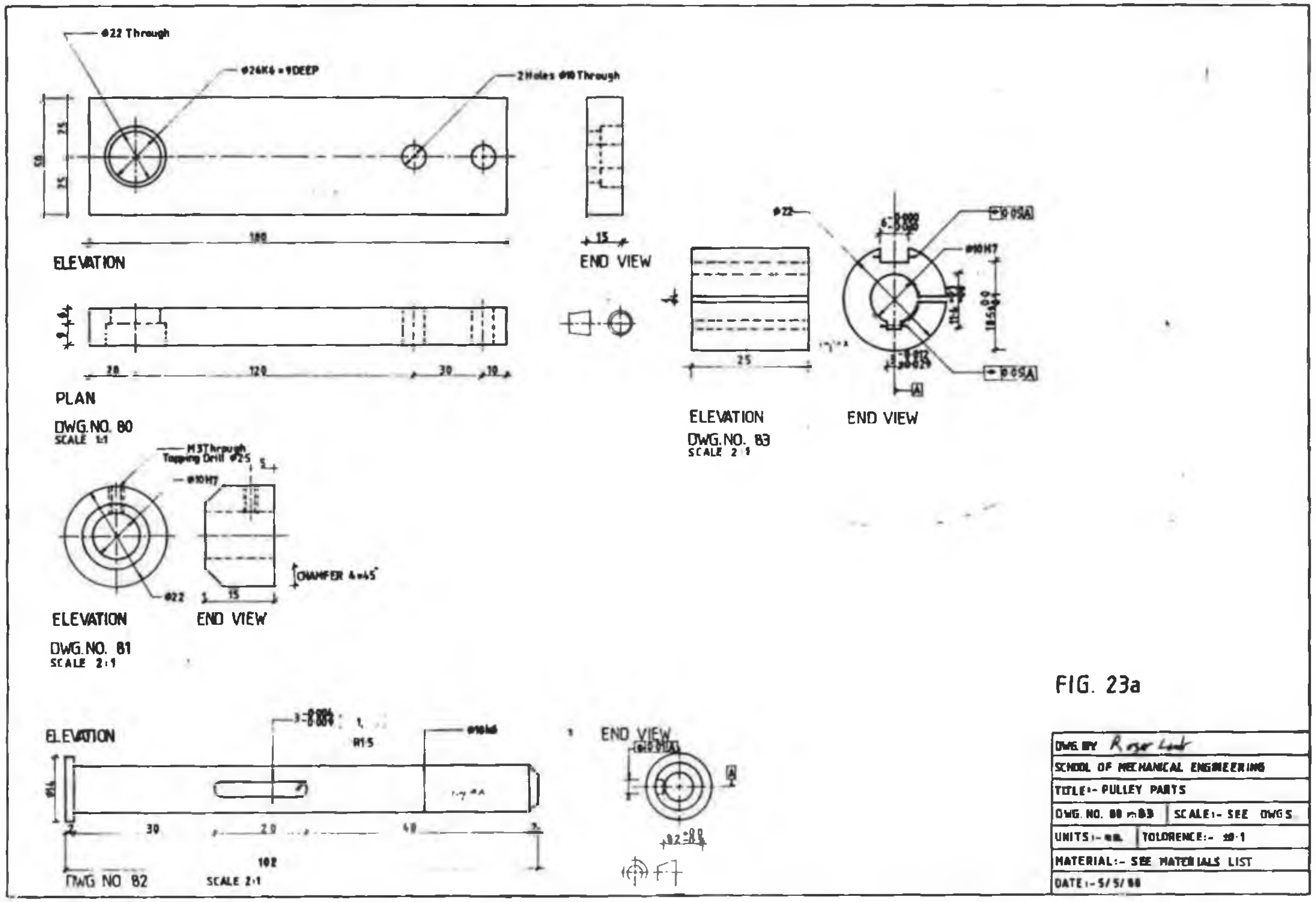

ø22 Through
ø26K6 × 9DEEP
2 Holes ø10 Through
ELEVATION
END VIEW
PLAN
DWG.NO. 80
SCALE 1:1
ELEVATION
END VIEW
DWG.NO. 83
SCALE 2:1
M3 Through
Tapping Drill ø2.5
ø10H7
CHAMFER 4×45°
ø22
ELEVATION
END VIEW
DWG.NO. 81
SCALE 2:1
ELEVATION
END VIEW
R15
ø10k6
DWG NO 82
SCALE 2:1
DWG BY Roger Lamb
SCHOOL OF MECHANICAL ENGINEERING
TITLE:- PULLEY PARTS
DWG. NO. 80 – 83
SCALE:- SEE DWGS
UNITS:- mm
TOLORENCE:- ±0·1
MATERIAL:- SEE MATERIALS LIST
DATE:- 5/5/88

FIG. 23a

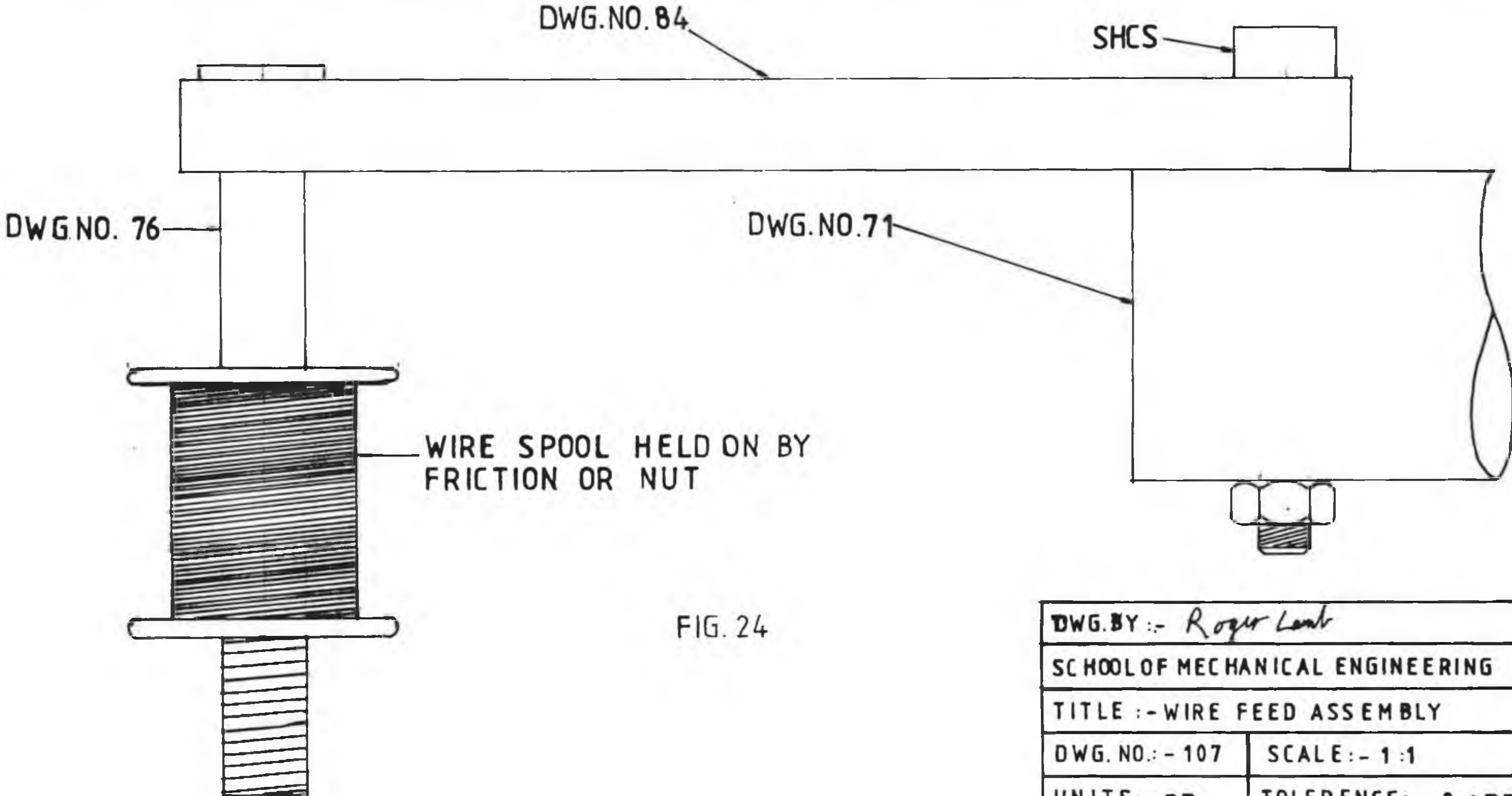


FIG. 24

DWG.BY :- Roger Lamb	
SCHOOL OF MECHANICAL ENGINEERING	
TITLE :- WIRE FEED ASSEMBLY	
DWG. NO.:- 107	SCALE:- 1:1
UNITS:- mm.	TOLERENCE: - 0.1 mm.
MATERIAL :- N/A	
DATE :- 25/5/89	

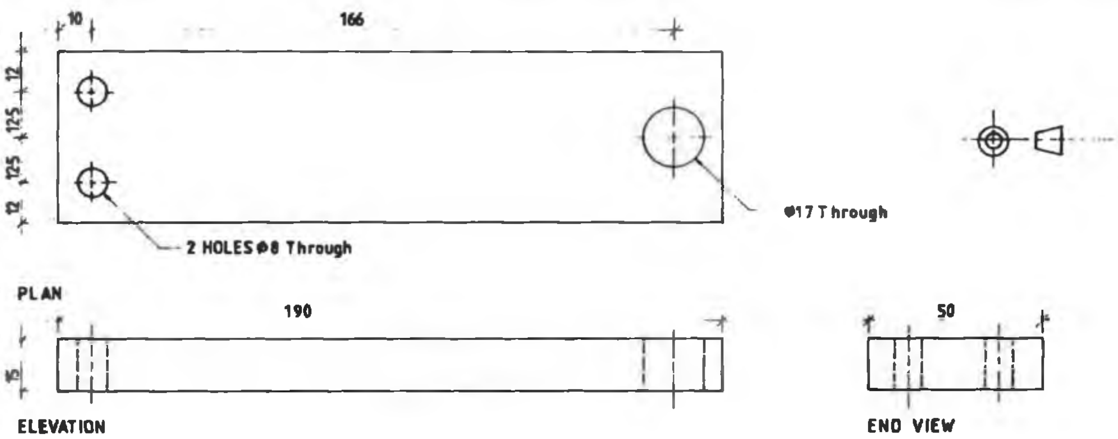
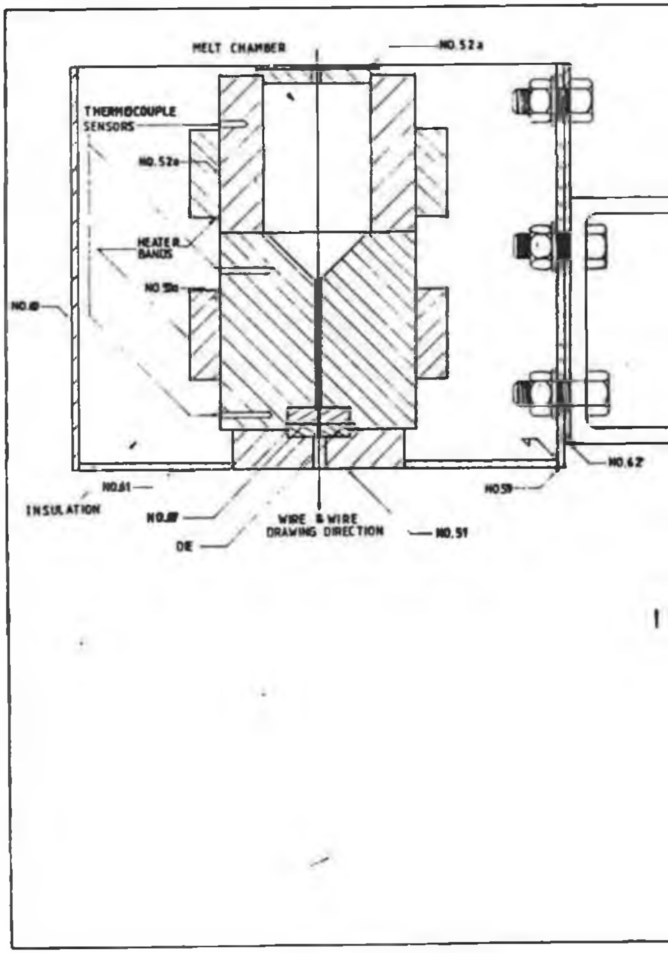


FIG. 24a

DWG. NO. 84	SCALE 1:1
DWG. BY:- Roger L[illegible]	
SCHOOL OF MECHANICAL ENGINEERING N.I.H.E.	
TITLE:-WIRE REEL SUPPORT	
UNITS:- mm.	TOLERENCE:- ±0·1 m
MATERIAL:- SEE MATERIALS LIST	
DATE:- 8/4/89	


MELT CHAMBER
NO.52a
THERMOCOUPLE SENSORS
NO.52a
HEATER BANDS
NO.51a
NO.61
INSULATION
DIE
WIRE & WIRE DRAWING DIRECTION
NO.51
NO.59
NO.62

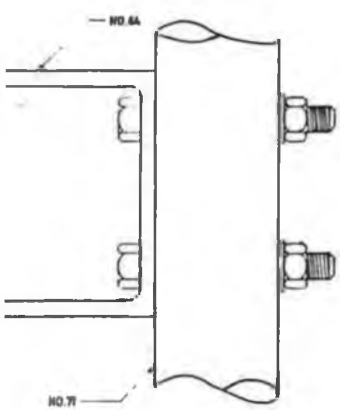
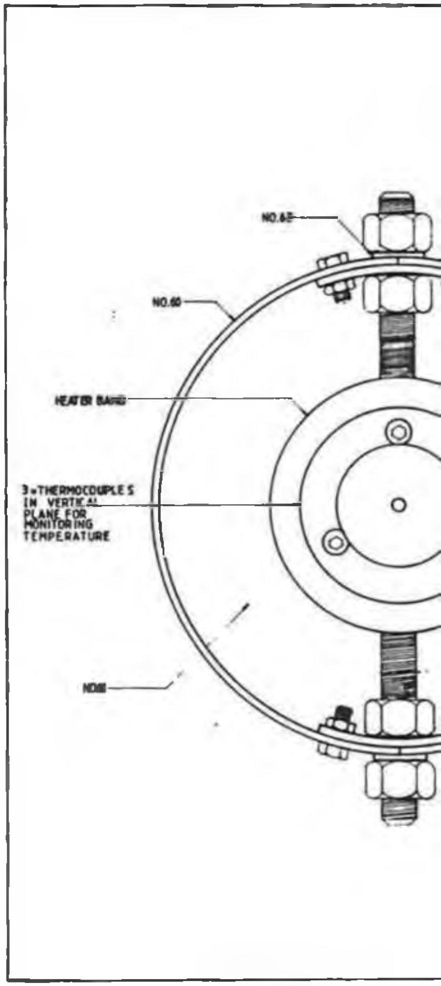


FIG. 25

DWG. BY:- Roger Lamb
SCHOOL OF MECHANICAL ENGINEER
TITLE:-DWG. BLOCK ASSEMBLY(ELEVATION)
DWG. NO:-100
SCALE: - 1:1
MATERIAL:-SEE DWG'S
DATE:- 26/6/ 88

62



NO.60
HEATER BAND
3×THERMOCOUPLES IN VERTICAL PLANE FOR MONITORING TEMPERATURE

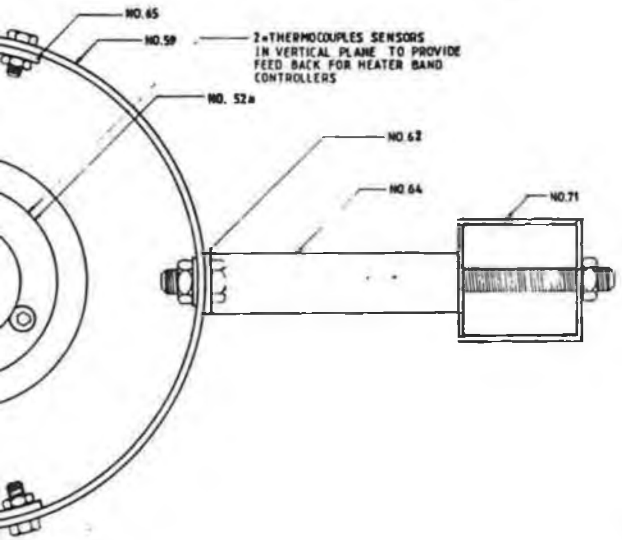
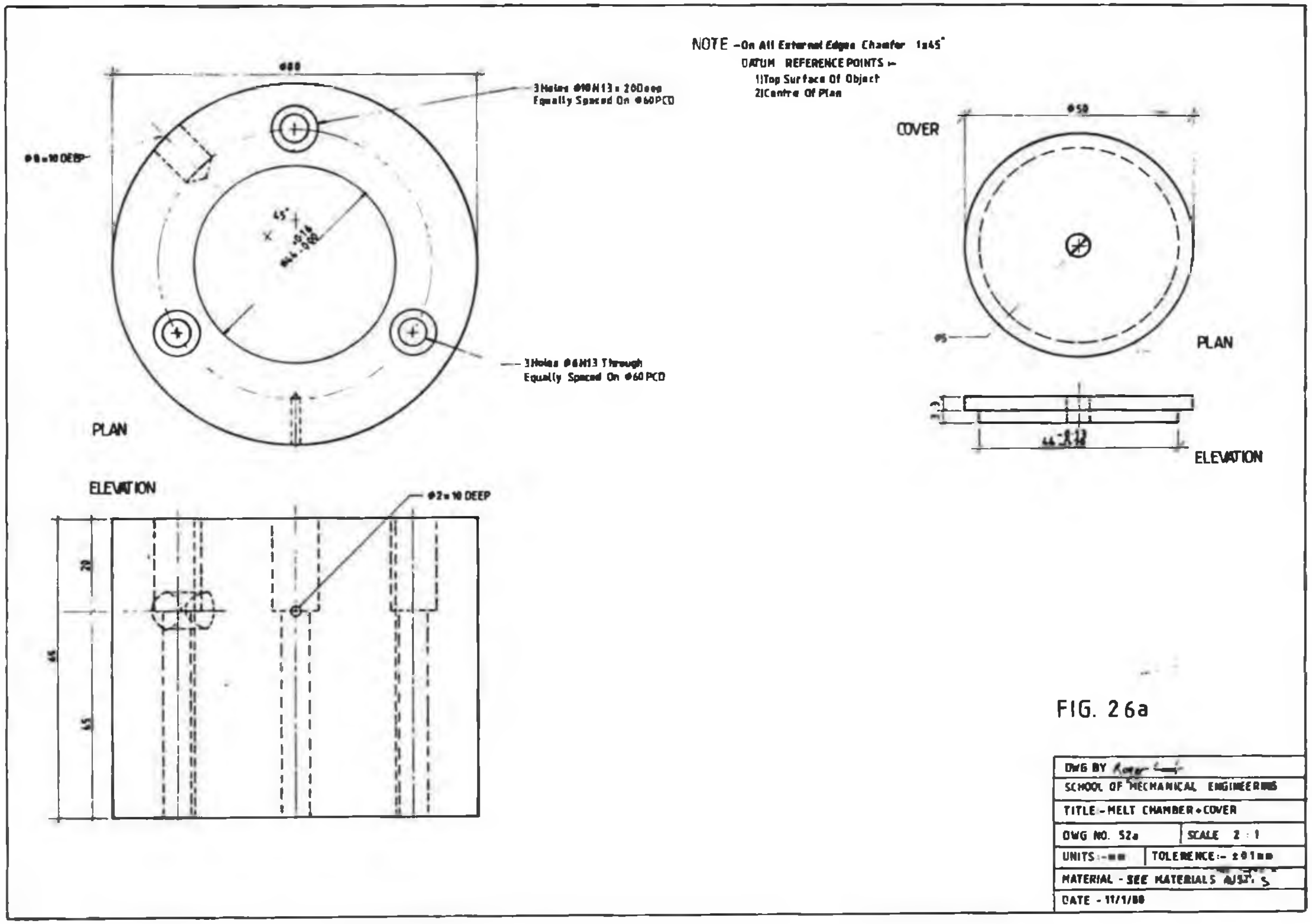
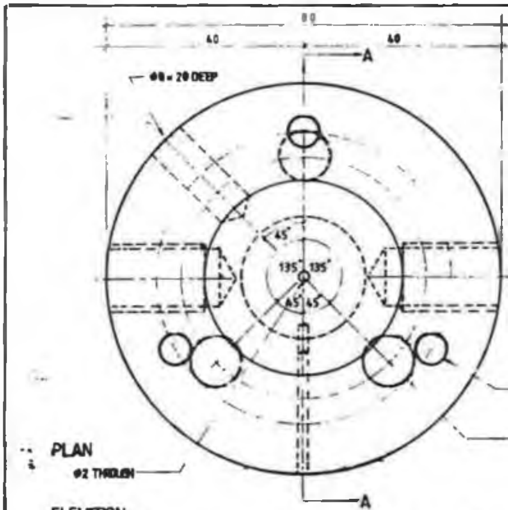


FIG. 26

DWG. BY:– Roger Lamb
SCHOOL OF MECHANICAL ENGINEERING
TITLE:- DWG BLOCK ASSEMBLY (PLAN)
DWG. NO.:– 101
SCALE:– 1 1
MATERIAL:– SEE DWG S
DATE:– 20/4/88


NOTE -On All External Edges Chamfer 1x45°
DATUM REFERENCE POINTS :-
1)Top Surface Of Object
2)Centre Of Plan
3Holes Ø10H13 x 20Deep
Equally Spaced On Ø60PCD
3Holes Ø6H13 Through
Equally Spaced On Ø60PCD
Ø80
PLAN
ELEVATION
Ø2 x 10 DEEP
20
45
COVER
Ø50
PLAN
ELEVATION
DWG BY
SCHOOL OF MECHANICAL ENGINEERING
TITLE - MELT CHAMBER + COVER
DWG NO. 52a
SCALE 2 : 1
UNITS :- mm
TOLERENCE :- ±0.1mm
MATERIAL - SEE MATERIALS LIST
DATE - 11/1/88
FIG. 26a



80
40
40
A
Φ8 x 20 DEEP
45°
135°
135°
45°
45°
PLAN
Φ2 THROUGH
A
ELEVATION
Φ40
Φ2 x 30 Deep
45°
13
13

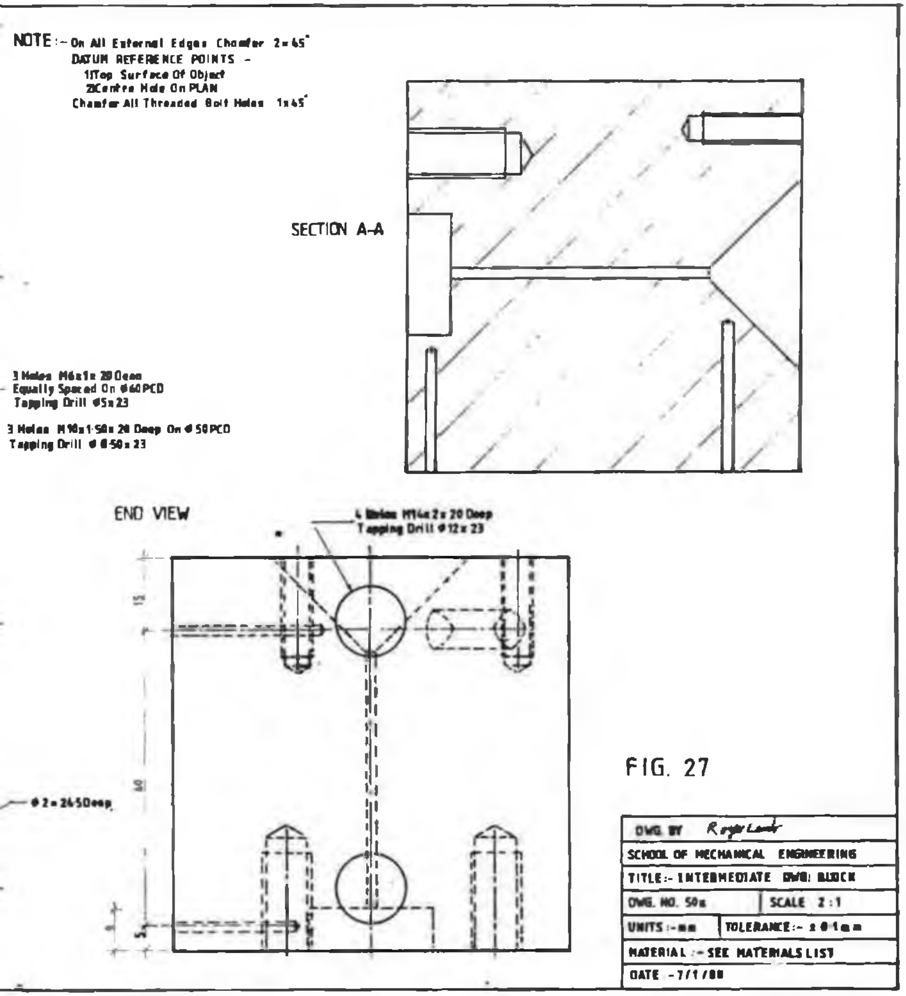

NOTE :- On All External Edges Chamfer 2×45°
DATUM REFERENCE POINTS -
1)Top Surface Of Object
2)Centre Hole On PLAN
Chamfer All Threaded Bolt Holes 1×45°
SECTION A-A
3 Holes M6×1×20 Deep
Equally Spaced On ϕ60PCD
Tapping Drill ϕ5×23
3 Holes M10×1·50×20 Deep On ϕ50PCD
Tapping Drill ϕ 8·50×23
END VIEW
4 Holes M14×2×20 Deep
Tapping Drill ϕ12×23
ϕ2×245Deep
DWG. BY
SCHOOL OF MECHANICAL ENGINEERING
TITLE:- INTERMEDIATE DWG: BLOCK
DWG. NO. 50a
SCALE 2:1
UNITS :- mm
TOLERANCE :- ±0·1mm
MATERIAL :- SEE MATERIALS LIST
DATE - 7/1/88

FIG. 27

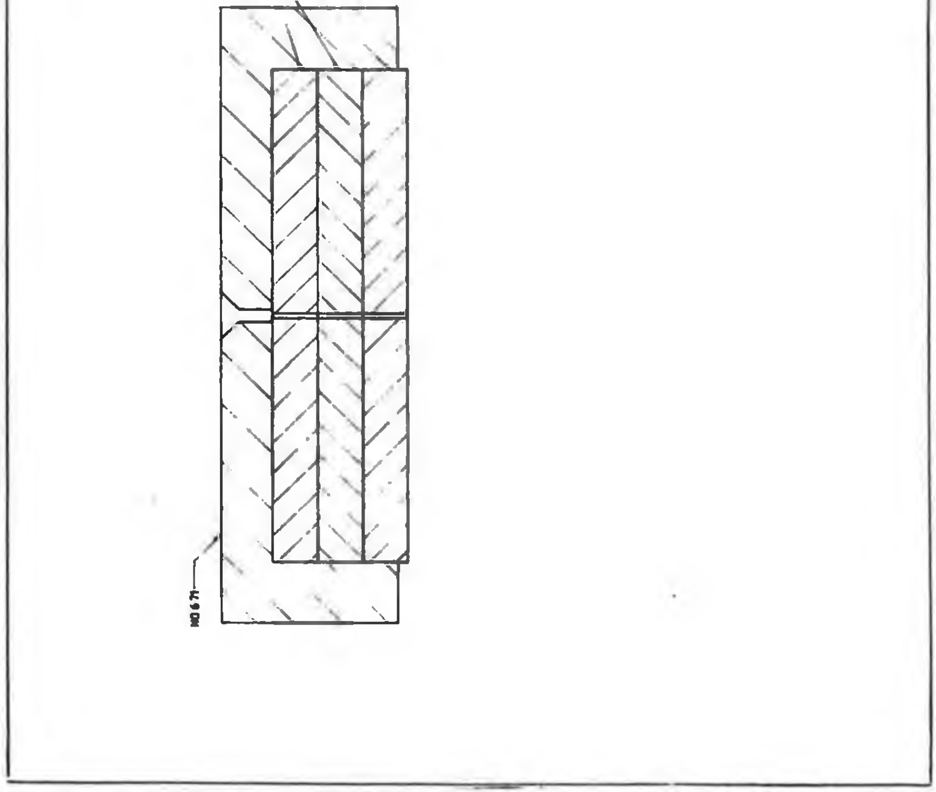

NO 6 71

FIG. 28

DWG BY - Roger Lamb	
SCHOOL OF MECHANICAL ENGINEERING N I H E	
TITLE -ASSEMBLY PRESSURE DIE	
DWG NO 67	SCALE 1:1
UNITS - mm	
MATERIAL - SEE MATERIALS LIST	
DATE - 5/1/89	

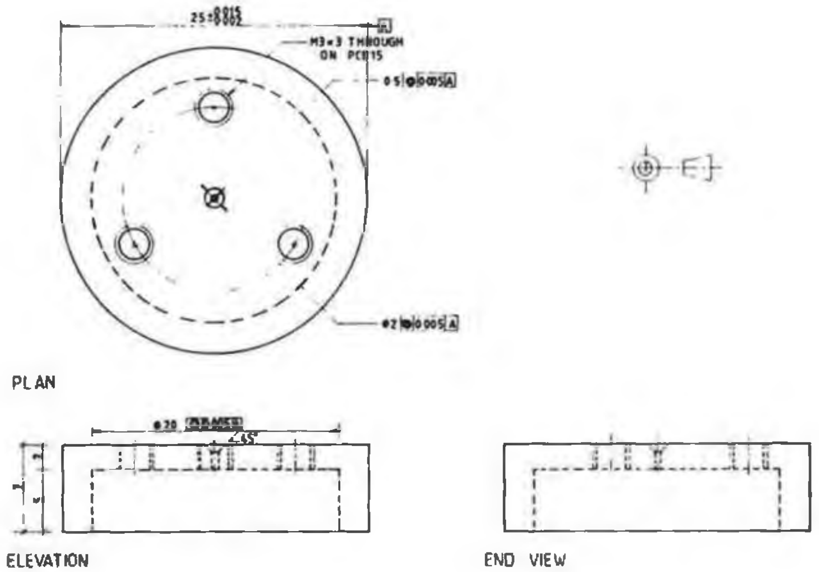


FIG. 28a

DWG BY:- Roger Lamb	
SCHOOL OF MECHANICAL ENGINEERING NIHE	
TITLE - PRESSURE RINGS HOUSING	
DWG NO. 671	SCALE 5:1
UNITS:- mm	TOLERANCE ±0.1 mm
MATERIAL - SEE MATERIALS LIST	
DATE:- 5/1/89	

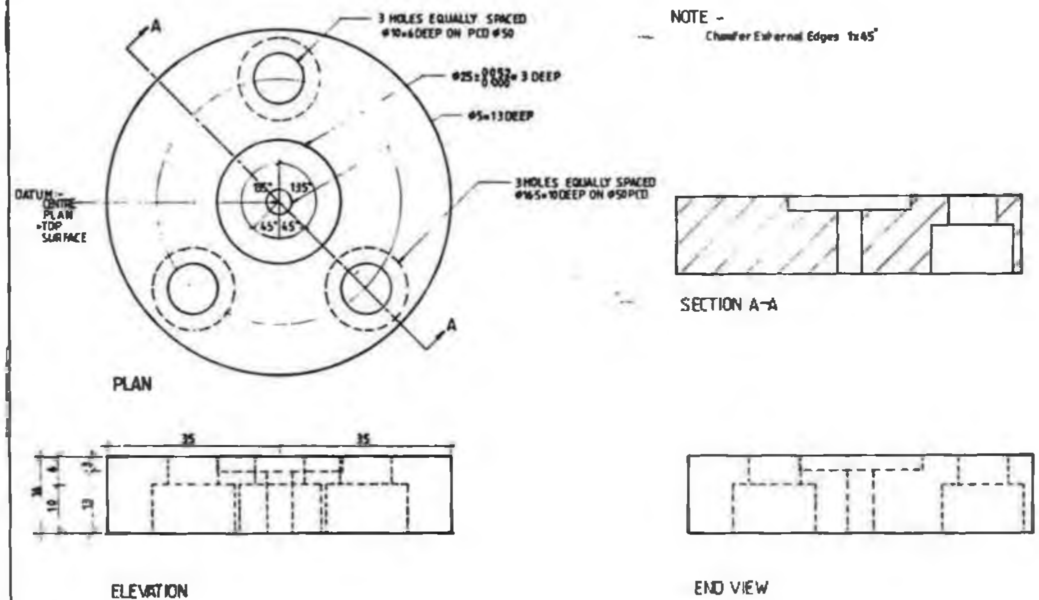


FIG. 29

MATERIAL:-'SEE MATERIALS LIST' 3	
UNITS .- mm	TOLERANCE ± 0.1 mm
TITLE:- DIE HOUSING	
DWG. NO. 51	SCALE 2:1
DWG. BY Roger Lamb	
SCHOOL OF MECHANICAL ENGINEERING NIHE	

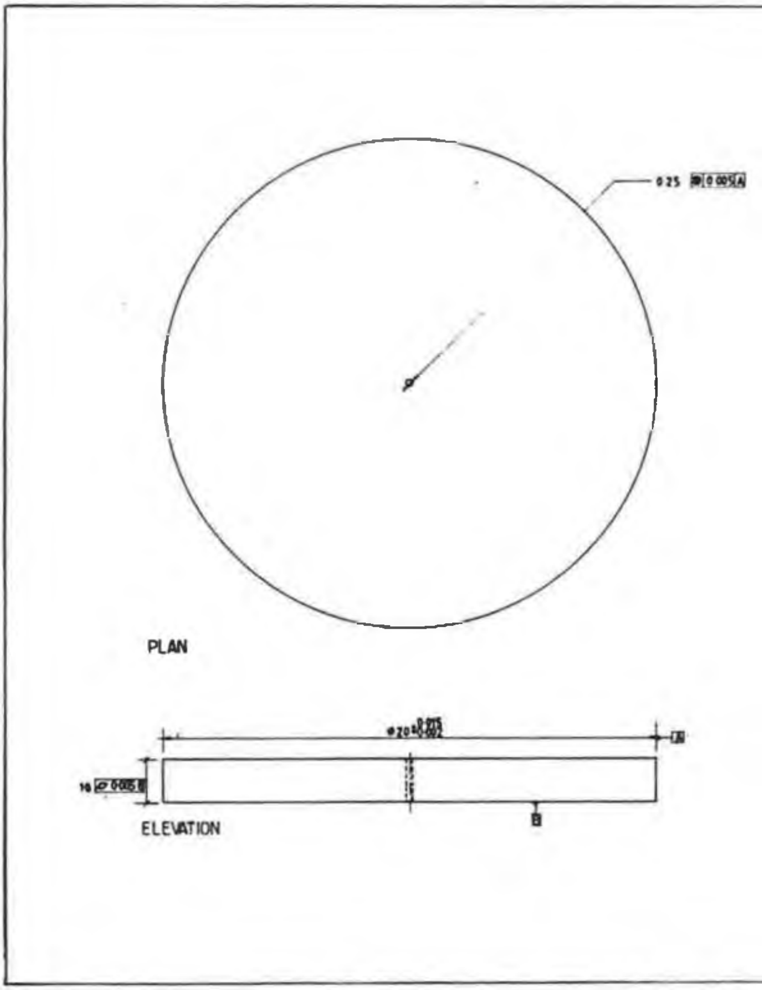

0.25 ⌭ 0.005 A
PLAN
ϕ20 +0.015 −0.002
A
16 ▱ 0.005 B
ELEVATION
B

FIG. 30

DWG BY :- [illegible]	
SCHOOL OF MECHANICAL ENGINEERING NIHE	
TITLE :- PRESSURE RINGS	
DWG. NO 672	SCALE :- 5:1
UNITS :- mm	TOLERANCE ± 0.1
MATERIAL :- SEE MATERIALS LIST	
DATE - 5/1/89	QUANTY - 3

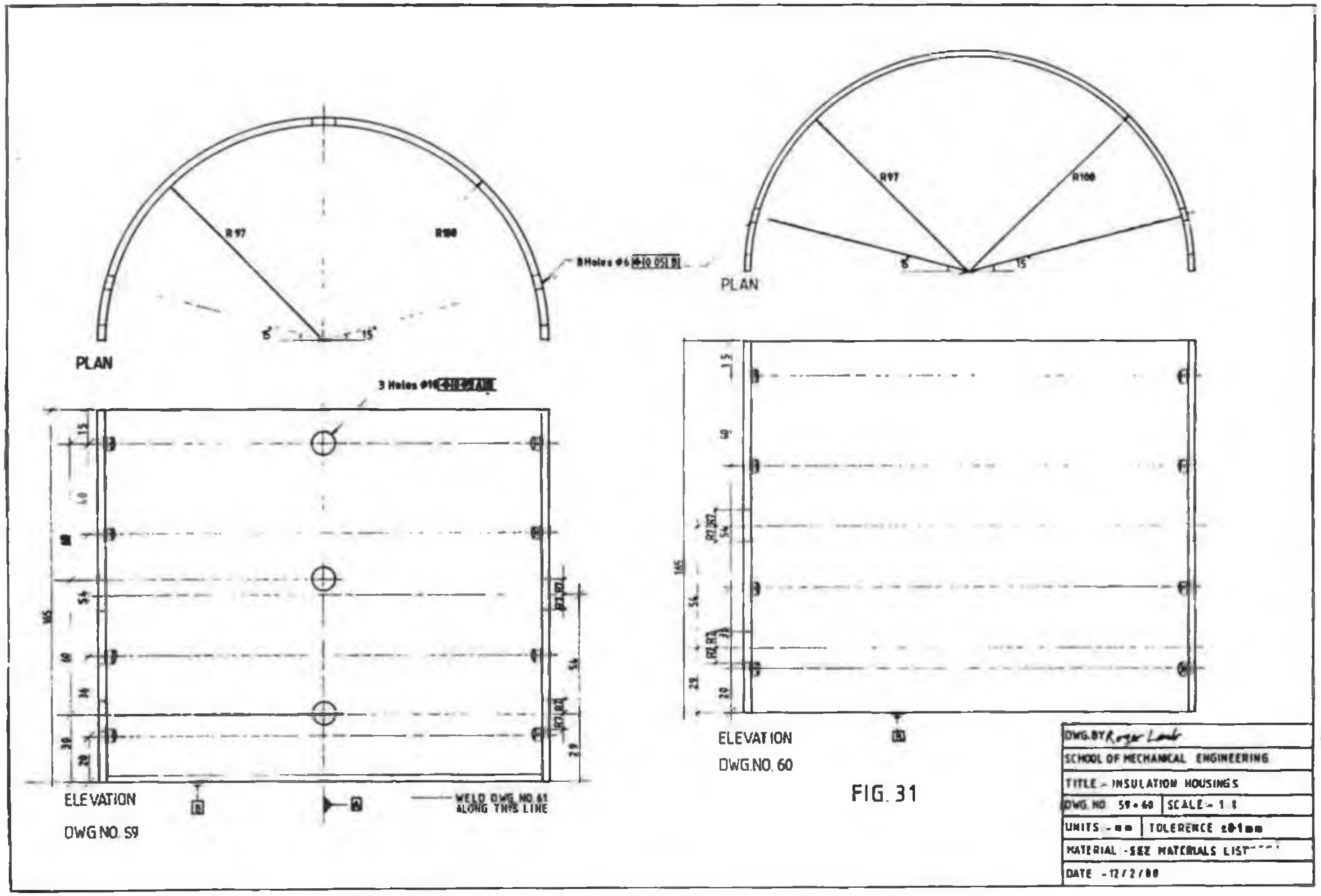
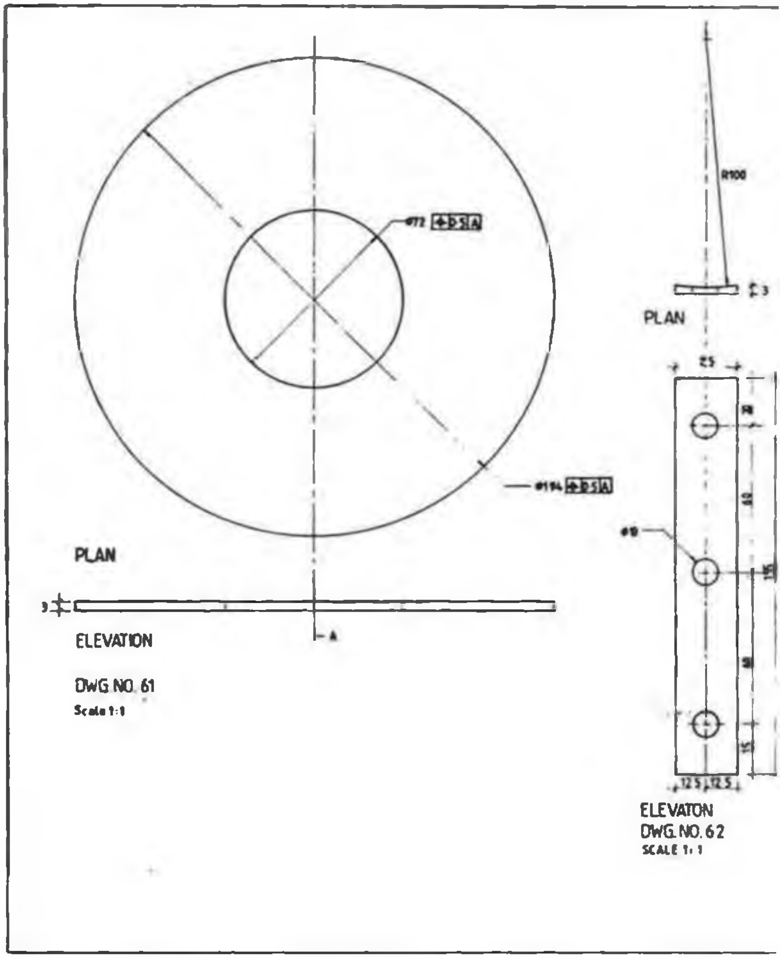
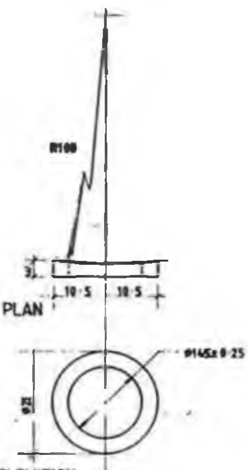

PLAN
R97
R100
8 Holes ⌀6
15°
15°
PLAN
R97
R100
15°
15°
3 Holes ⌀16
ELEVATION
DWG.NO. 59
WELD DWG NO 61 ALONG THIS LINE
ELEVATION
DWG.NO. 60
DWG.BY Roger Lamb
SCHOOL OF MECHANICAL ENGINEERING
TITLE - INSULATION HOUSINGS
DWG.NO 59+60
SCALE - 1:1
UNITS - mm
TOLERENCE ±0.1mm
MATERIAL - SEE MATERIALS LIST
DATE - 12/2/00

FIG. 31



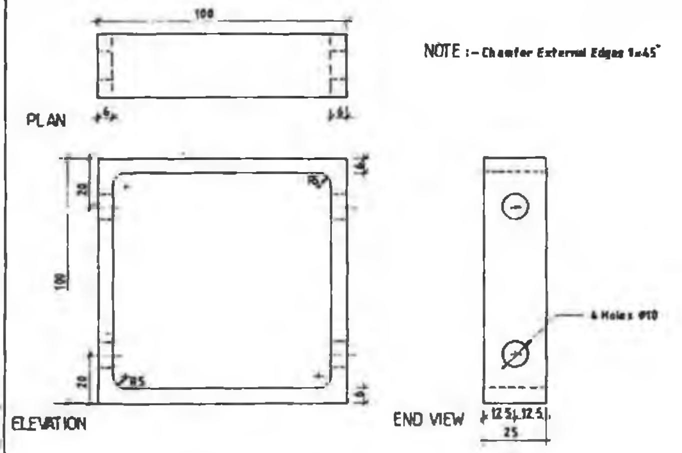
PLAN
ELEVATION
DWG NO. 61
Scale 1:1
R100
PLAN
25
ELEVATON
DWG. NO. 62
SCALE 1:1



ELEVATION
DWG.NO. 63
Scale 2:1

FIG. 32

DWG BY	
SCHOOL OF MECHANICAL ENGINEERING	
TITLE :- DRAWING BLOCK PARTS	
DWG. NO. 61 + 62 + 63	TOLERENCE ± 0·1 mm
MATERIAL :- SEE MATERIALS LIST	
UNITS :- mm	SCALE - SEE DWG.
DATE - 10/2/88	



DWG NO 64
Scale 1:1

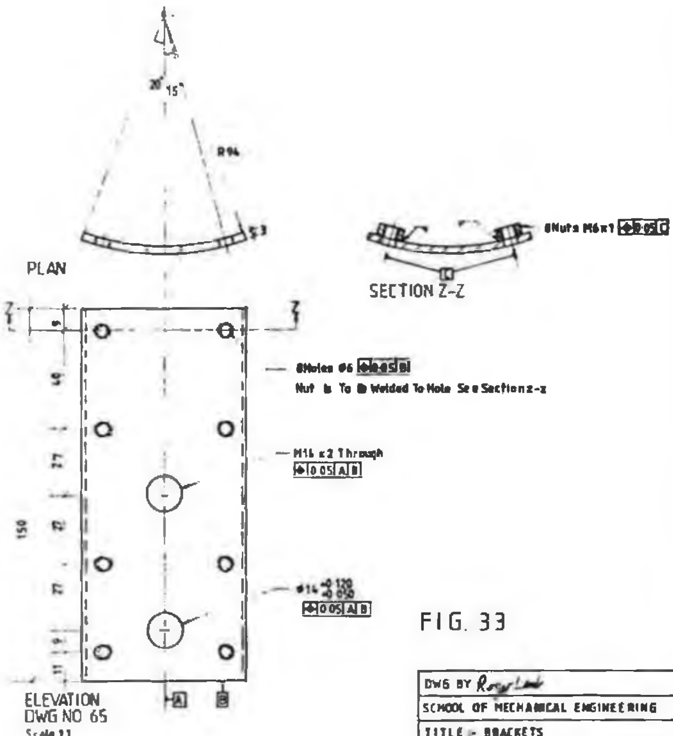


FIG. 33

DWG BY Roger Lamb	
SCHOOL OF MECHANICAL ENGINEERING	
TITLE - BRACKETS	
DWG NO. 64 + 65	SCAE - SEE DRAWING
UNITS - mm	TOLERENCE ±0.1 mm
MATERIAL - SEE MATERIALS LIST	
DATE - 19/2/88	

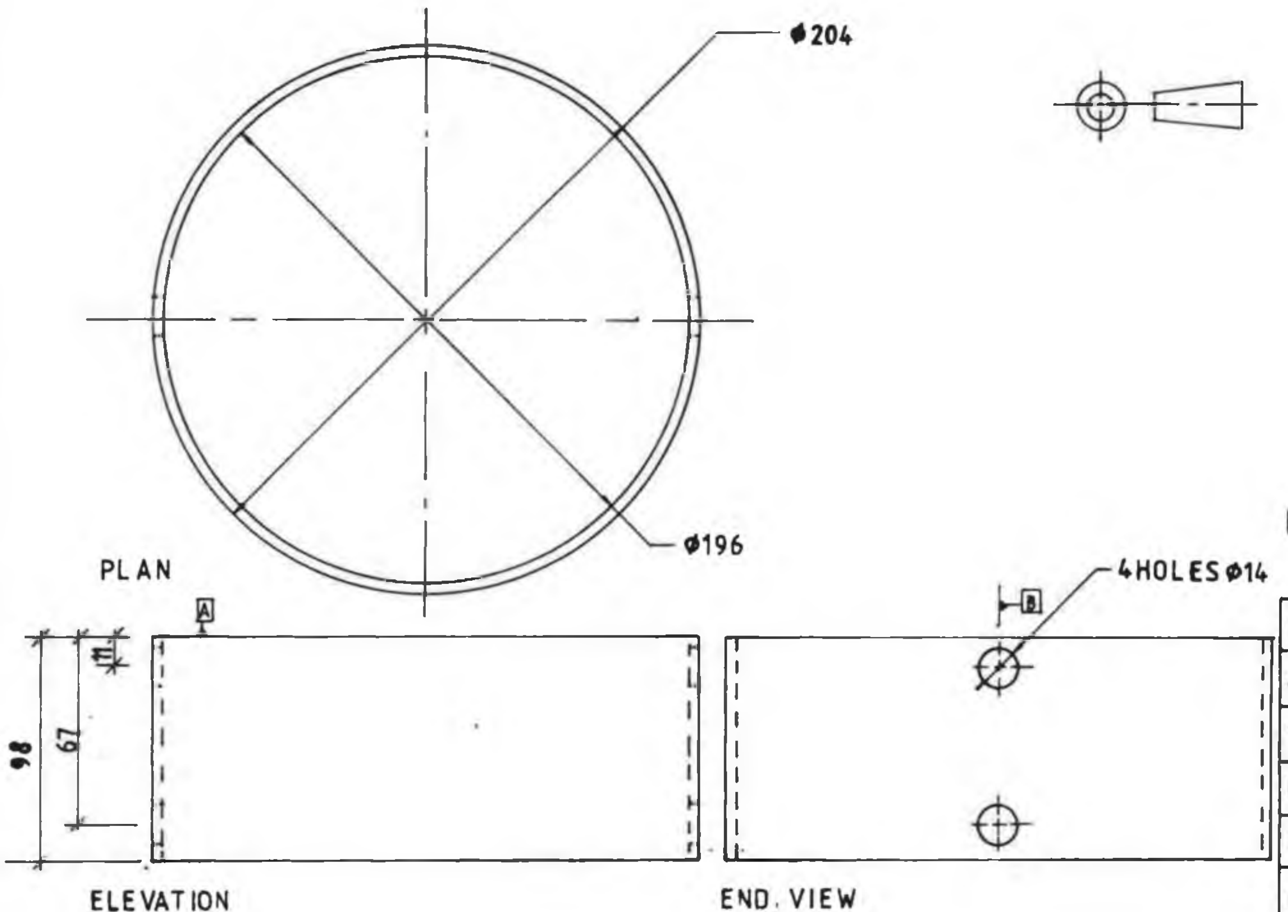
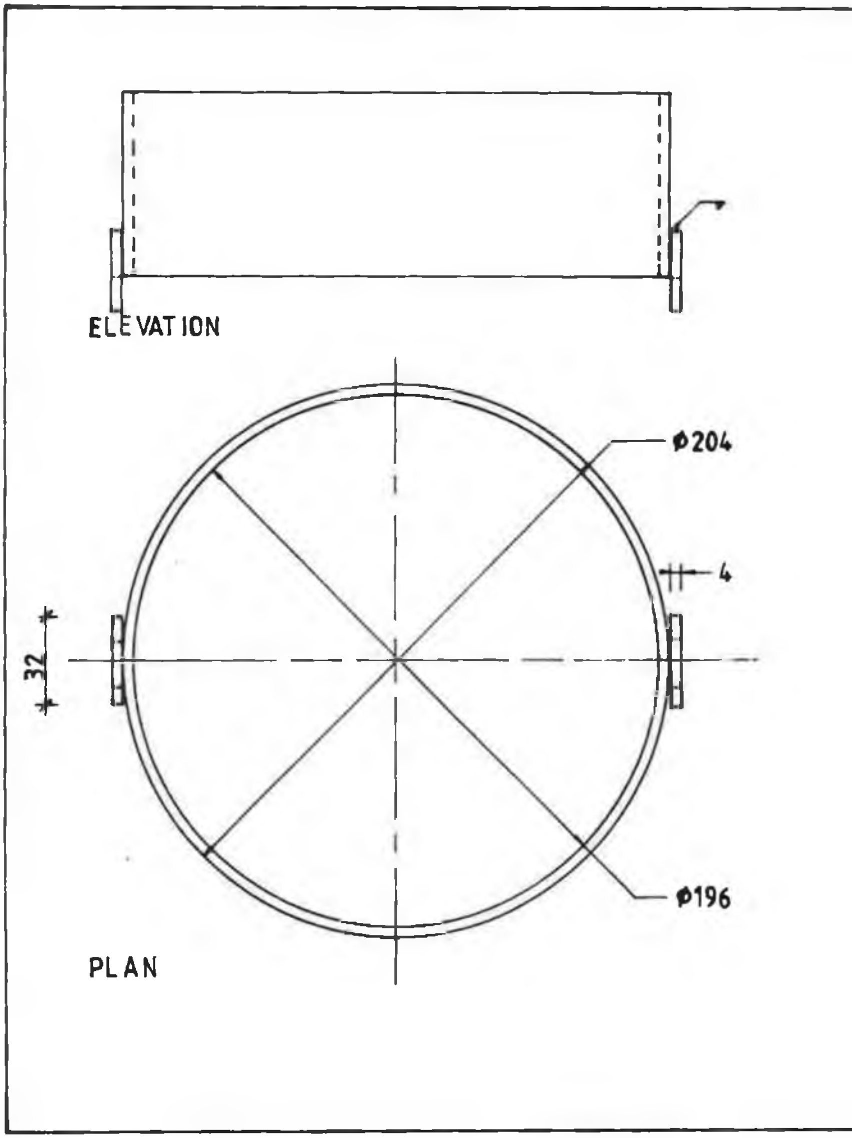


FIG. 34

DWG. BY :- Roger Lamb	
SCHOOL OF MECHANICAL ENGINEERING	
TITLE :- INSULATION HOUSING FOR P.D.C.	
DWG. NO. : - 59a	SCALE :- 1 : 2
UNITS :- mm.	TOLERANCE :- ±0·1 mm.
MATERIAL :- SEE MATERIALS TABLE	
DATE :- 15/9/88	


ELEVATION
ϕ204
4
32
ϕ196
PLAN

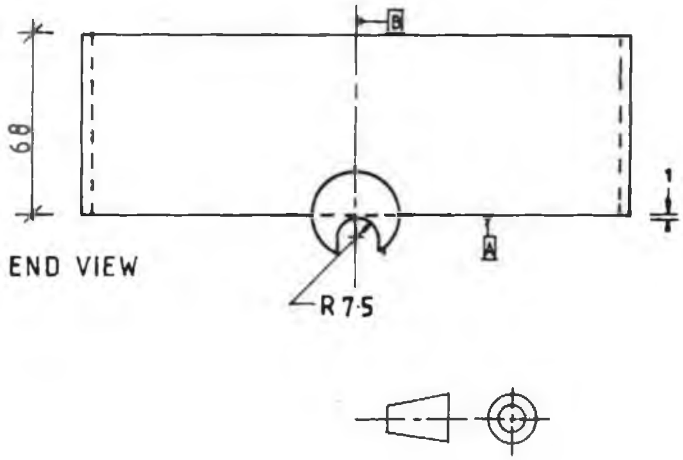
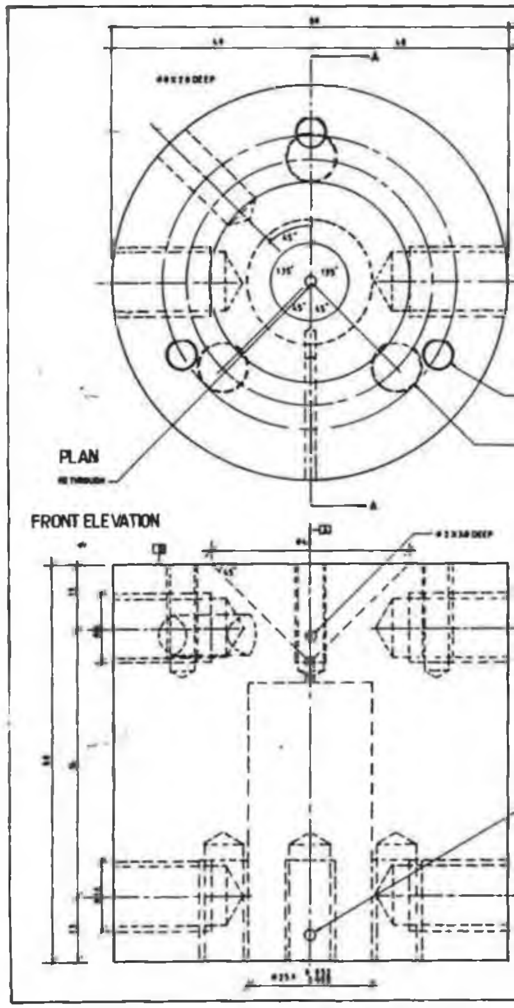


FIG. 35

DWG BY :- Roger Lewis	
SCHOOL OF MECHANICAL ENGINEERING	
TITLE :- INSULATION HOUSING FOR MELT C/BER	
DWG. NO. :- 60a	SCALE :- 1 : 2
UNITS :- mm.	TOLERANCE :- ±0·1 mm.
MATERIAL :- SEE MATERIALS TABLE	
DATE :- 15/9/88	


PLAN
FRONT ELEVATION

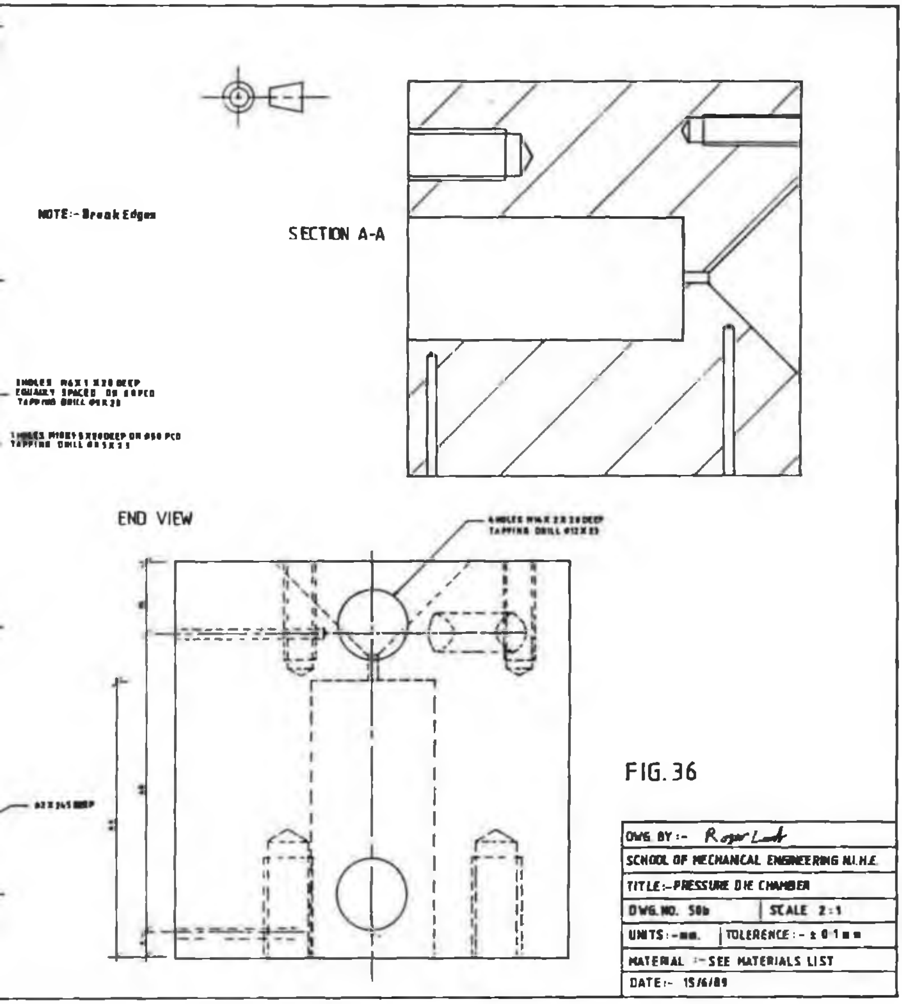
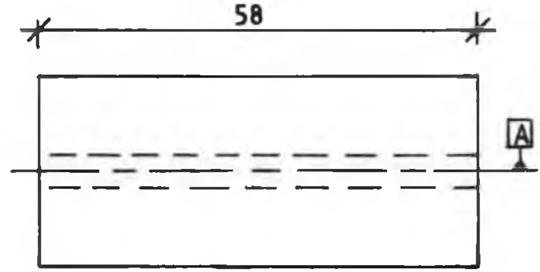
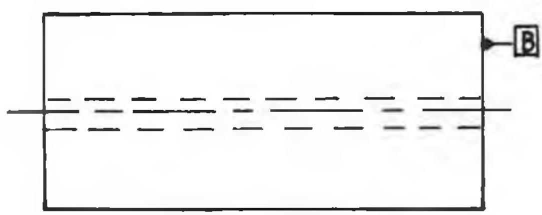

NOTE:- Break Edges
SECTION A-A
END VIEW
DWG BY :- Roger Lock
SCHOOL OF MECHANICAL ENGINEERING N.I.H.E.
TITLE:- PRESSURE DIE CHAMBER
DWG. NO. 50b
SCALE 2:1
UNITS:- mm.
TOLERENCE:- ± 0·1 mm
MATERIAL :- SEE MATERIALS LIST
DATE:- 15/6/89

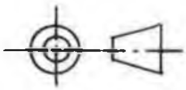
FIG. 36

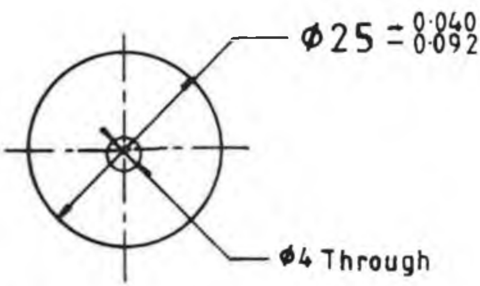


PLAN



ELEVATION

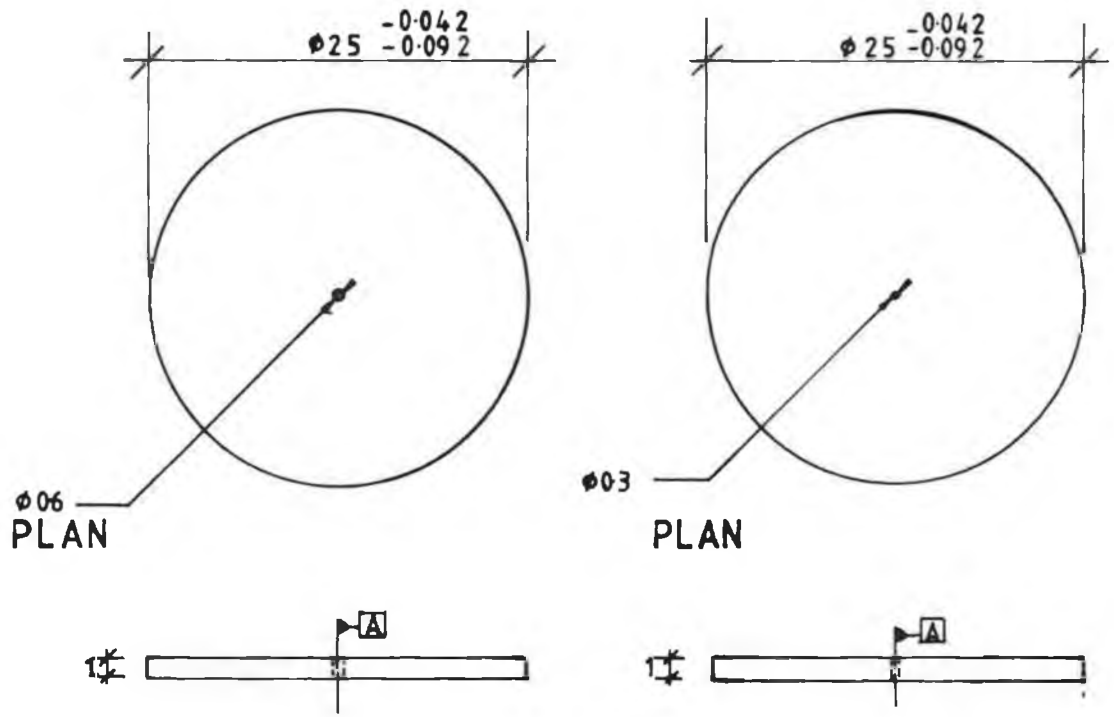




END VIEW

FIG. 37

DWG. BY:- Roger Lamb	
SCHOOL OF MECHANICAL ENGINEERING N.I.H.E	
TITLE:- INSERT HOLDER FOR P.D.C.	
DWG. NO. :- 71b	SCALE:- 1 :1
UNITS :- mm	TOLERENCE :- ±0·01 mm
MATERIAL:-SEE MATERIALS LIST	
DATE :- 16/6/89	



ELEVATION

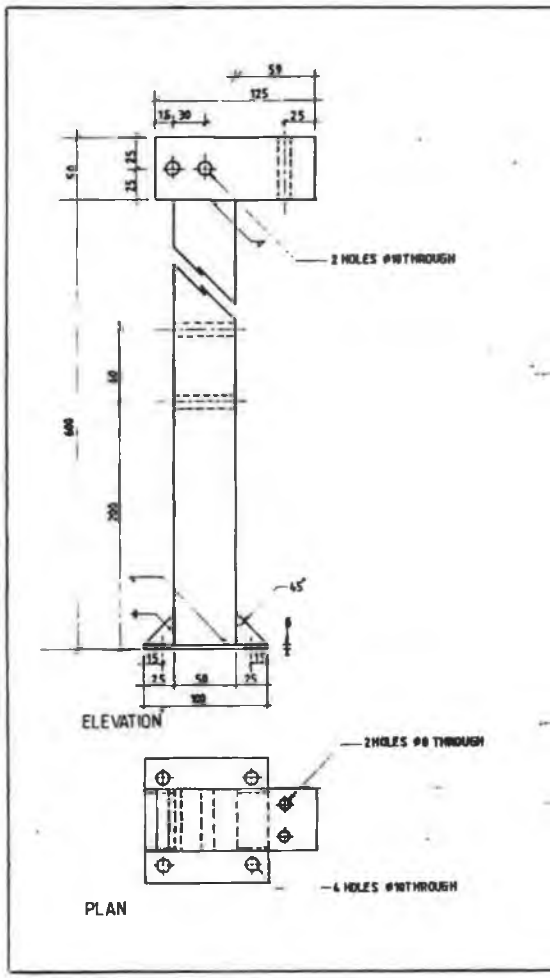
DWG.NO.:- 71c

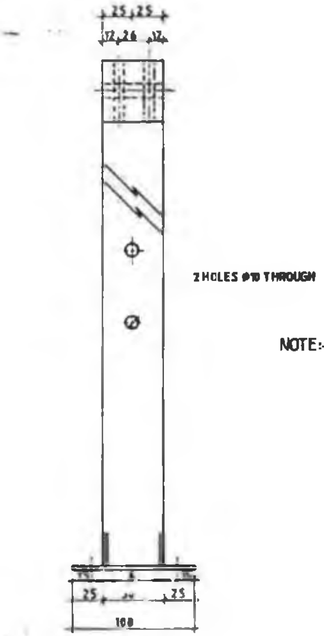
ELEVATION

DWG. NO. :-71d

FIG. 38

DWG. BY:- Roger Lamb	
SCHOOL OF MECHANICAL ENGINEERING	
TITLE :-DIE INSERTS	
DWG.NO.71c +71d	SCALE:- 1:2
UNITS:- mm.	TOLERENCE:- ± 0·01mm.
MATERIAL :-TOOL STEEL OR MILD STEEL	
DATE:- 29/6/89	


2 HOLES Ø10 THROUGH
2 HOLES Ø8 THROUGH
4 HOLES Ø10 THROUGH
45°
ELEVATION
PLAN

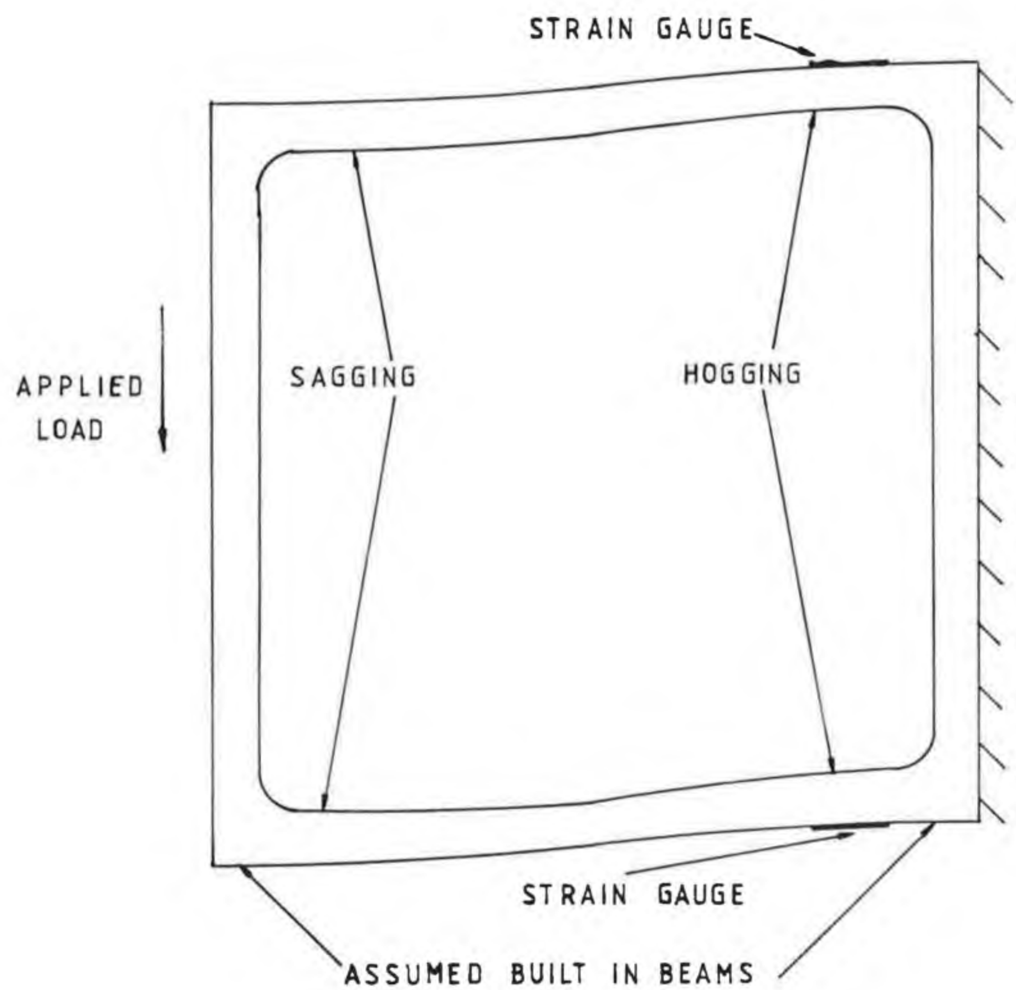


NOTE:– CHAMFER ROUGH EDGES 1×45°
PLUS BLANK OPEN ENDS OF BOX SECTION

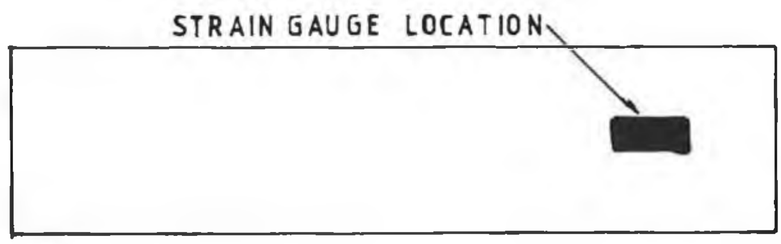
END VIEW

FIG. 39

DWG BY:– Roger Lamb	
SCHOOL OF MECHANICAL ENGINEERING	
TITLE:– DWG BLOCK STAND	
DWG. NO:– 71	SCALE:– 1:2
UNITS:– mm	TOLORENCE:– ±0.5
MATERIAL:– 50×50×2 BOX SECTION – 6mm PLATE	
DATE:– 12/5/89	

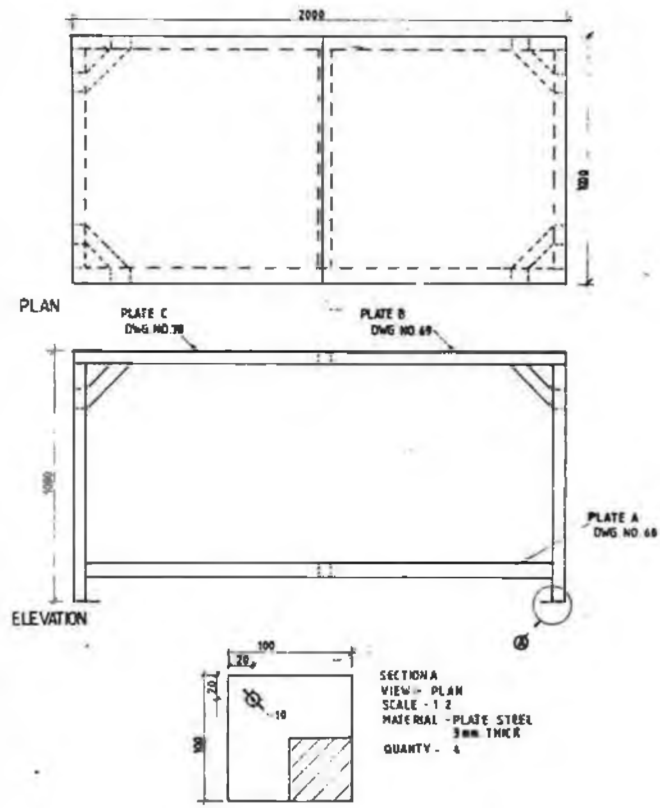


ELEVATION

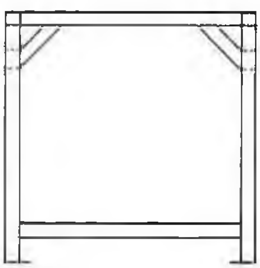


PLAN

FIG.40SCHEMATIC VIEW OF LOAD
MEASURING DEVICE



2000
PLAN
PLATE C
DWG NO.70
PLATE B
DWG NO.69
1000
PLATE A
DWG NO.68
ELEVATION
100
20
20
10
100
SECTION A
VIEW - PLAN
SCALE - 1:2
MATERIAL - PLATE STEEL
3mm THICK
QUANTY - 4



END VIEW

FIG. 41

DWG. BY [illegible]	
SCHOOL OF MECHANICAL ENGINEERING	
TITLE - DRAWING BENCH	
DWG NO 66	SCALE:- 1:10
UNITS:- mm	JOINTS:- WELDED (FILLET)
MATERIAL:- BOX SECTION 50 x 50 x 2	
DATE 15/4/88	

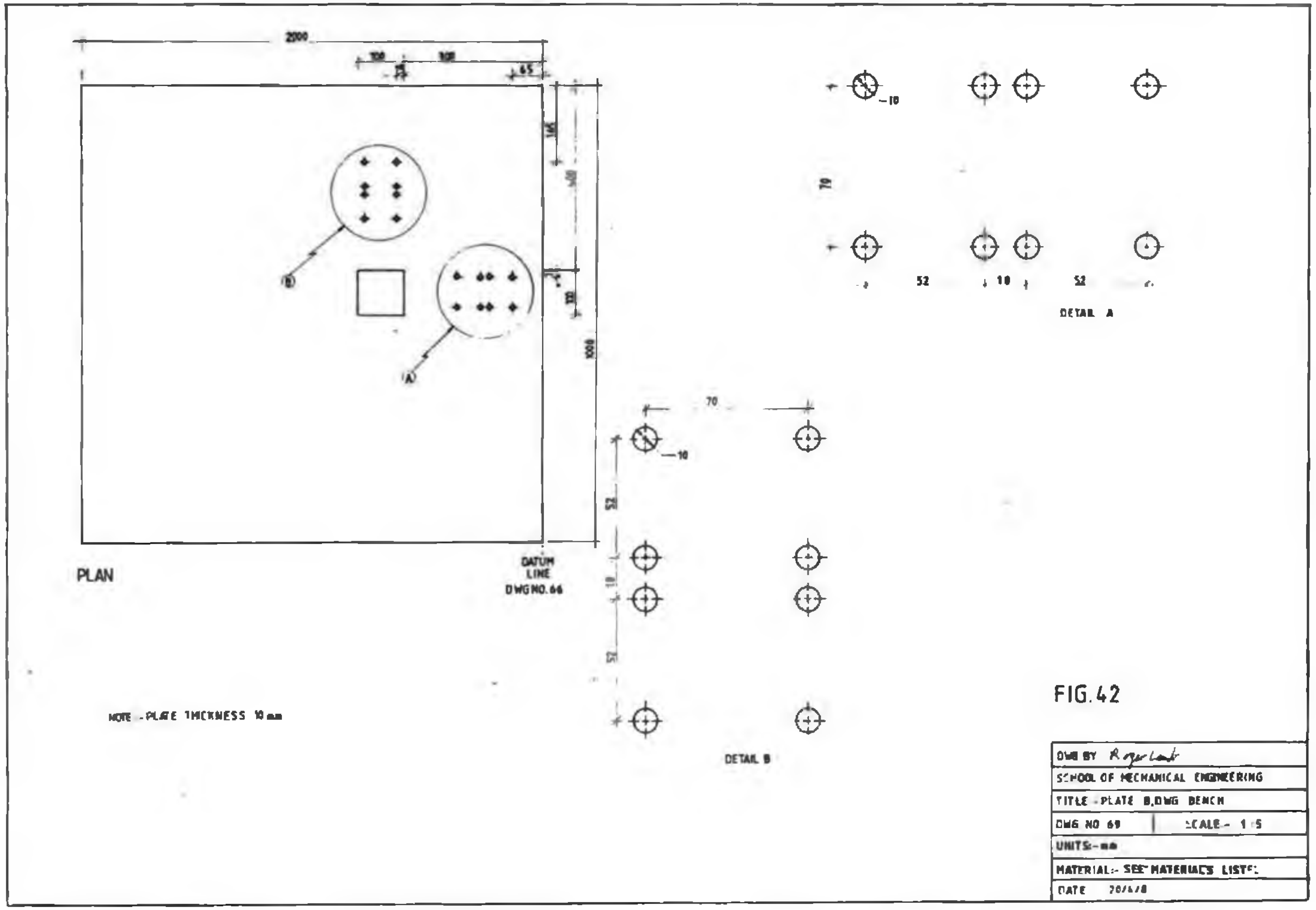

2000
100
100
25
65
PLAN
DATUM LINE
DWG NO. 66
NOTE - PLATE THICKNESS 10 mm
DETAIL A
DETAIL B
DWG BY Roger Lamb
SCHOOL OF MECHANICAL ENGINEERING
TITLE - PLATE B, DWG BENCH
DWG NO 69
SCALE - 1:5
UNITS:- mm
MATERIAL:- SEE MATERIALS LIST
DATE 20/6/78

FIG. 42

MATERIALS TABLE 1

Dwg. No.	Material	Quantity	Requires Size (mm^3)	Mass (kg)
50b	Ovar Supreme	1	ϕ80*80	3.13
51	Ovar Supreme	1	ϕ70*16	0.48
52a	Ovar Supreme	1	ϕ80*65	2.548
	Ovar Supreme	1	ϕ50*6	0.082
53	Gun Barrell	2	ϕ60*450	0.534
53a	Gun Barrell	1	ϕ60*225	1.31
54	UHB11	4	ϕ30*30	0.066
55	UHB11	4	ϕ155*36	0.436
56	Gun Barrell	2	ϕ165*450	4.79
56a	Gun Barrell	1	ϕ150*265	11.161
57	UHB11	2	ϕ200*20	1.91
57a	UHB11	2	ϕ125*20	4.9
58,58a	UHB11	1	ϕ30*430	2.34
59	Steel Plate	1	ϕ350*165*3	1.213
59a	Mild Steel	1	ϕ205*100*5	1.921
60	Steel Plate	1	ϕ350*165*3	1.213
60a	Mild Steel	1	ϕ205*70*5	1.333
61	Steel Plate	1	ϕ194*3	0.596
62	UHB11	1	155*25*3	0.090
63	UHB11	4	ϕ21*3	0.004
64	UHB11	1	100*100*25	0.440
65	Steel Plate	2	150*150*3	0.259
66	Box Section 50*50*2	1	Length 20m.	≈ 60
671	Ovar Supreme	1	ϕ25*7	0.016
672	Ovar Supreme	3	ϕ20*2	0.004
68	Steel Plate	1	1000*1000*10	78.00
69	Steel Plate	1	2000*1000*10	156.00
71	Box Section 50*50*2	1	Length 750	1.535
	Steel Plate		100*200*6	
71b	Mild Steel	1	ϕ25*58	0.216
71c,71d	Mild Steel	1	ϕ25*2	0.004
711	UHB11	2	220*60*40	3.325
72	UHB11	2	220*120*40	6.335
73	UHB11	2	210*36*18	1.645
74	UHB11	1	70*50*15	0.315
75	UHB11	1	70*50*15	0.315
76	Impax	1	ϕ20*120	0.185
77	UHB11	1	60*50*150	0.341
78	UHB11	1	ϕ5*16	0.002
79	UHB11	1	ϕ25*6	0.018
80	UHB11	1	180*50*15	1.009
81	UHB11	1	ϕ22*15	0.031
82	Impax	1	ϕ14*105	0.063
83	UHB11	1	ϕ25*25	0.051
84	Mild Steel	1	170*50*15	0.933

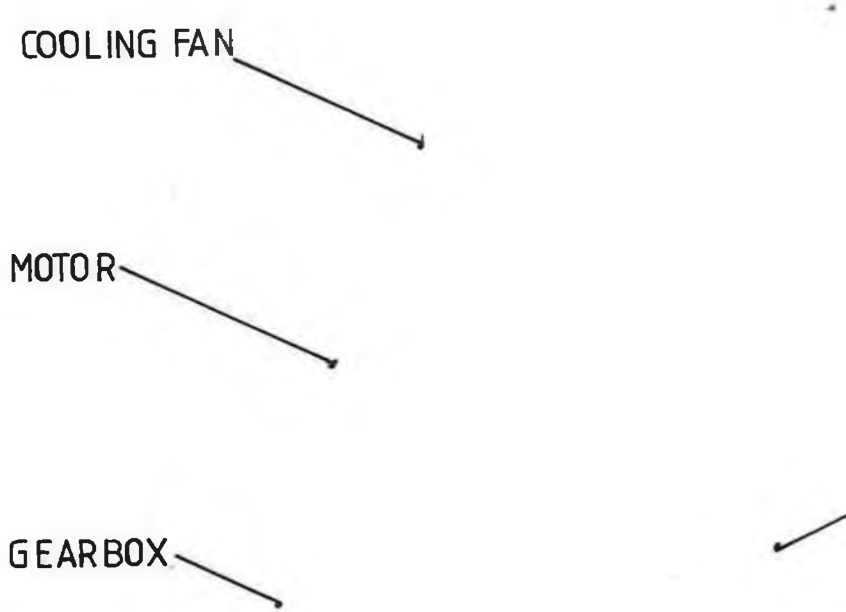
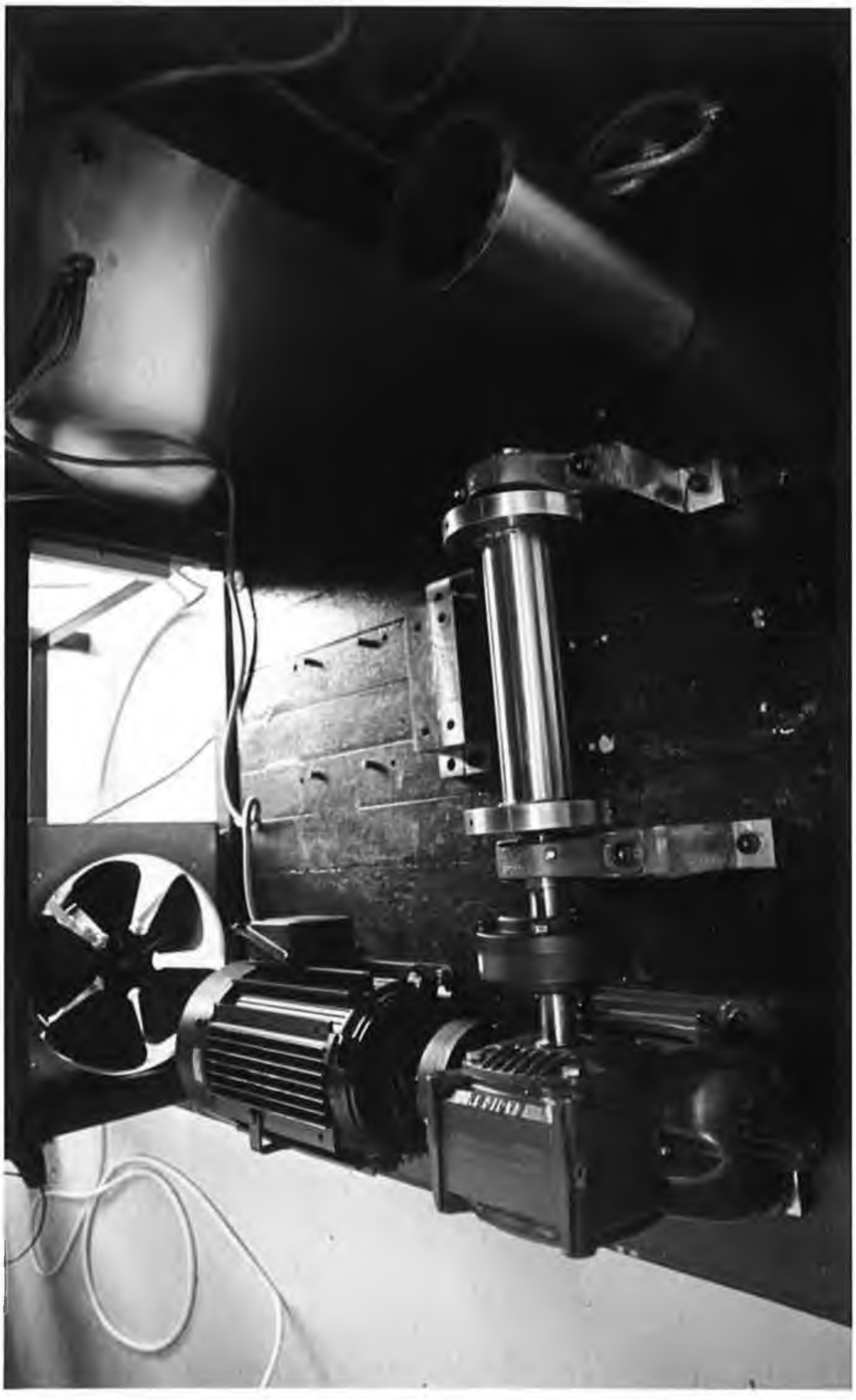

COOLING FAN
MOTOR
GEARBOX

PHOTO 1

SMALL BULL BLOCK

LARGE BULL BLOCK
SHELL



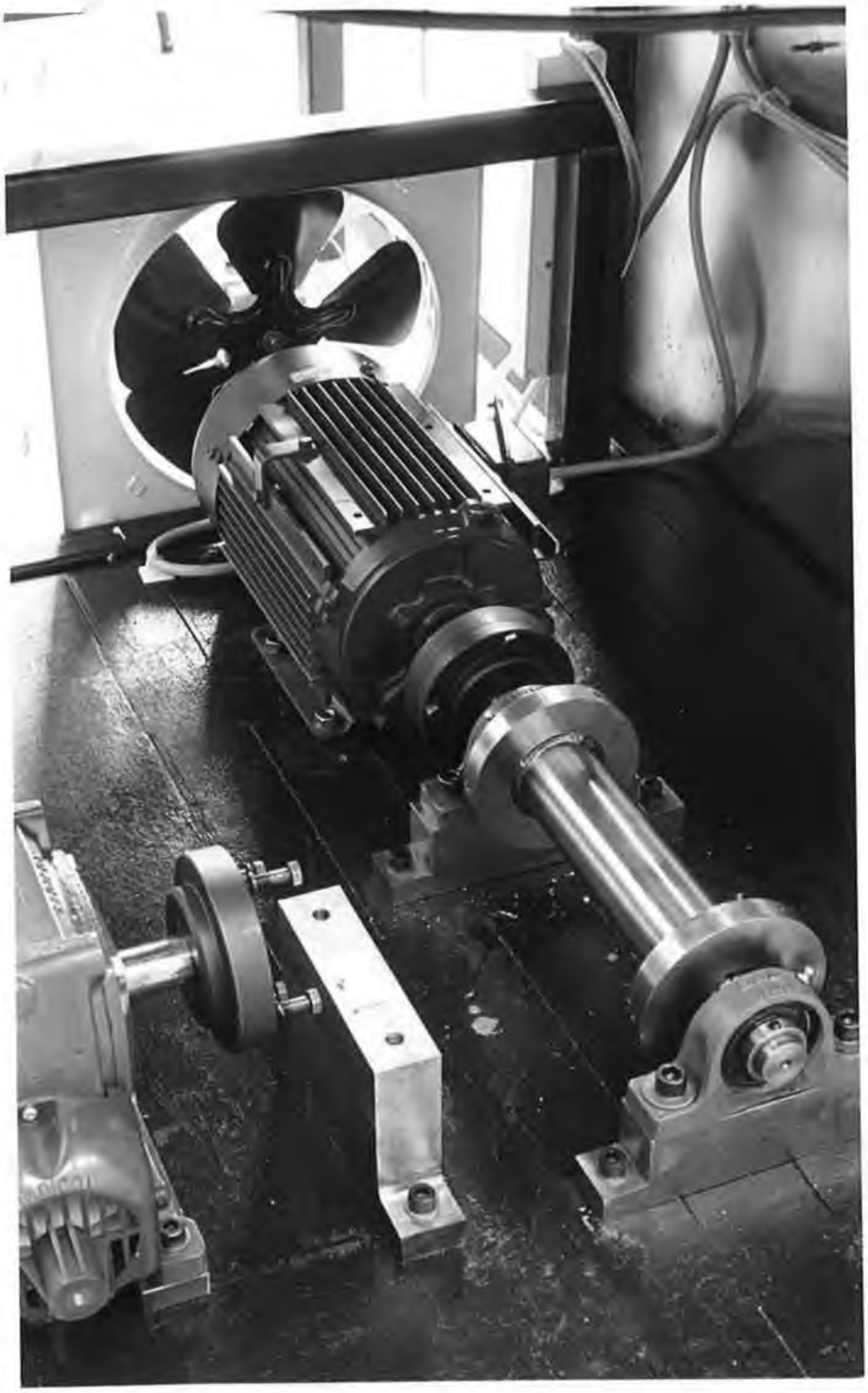
COOLING FAN

MOTOR

SMALL BULL
BLOCK

GEARBOX

PHOTO 2



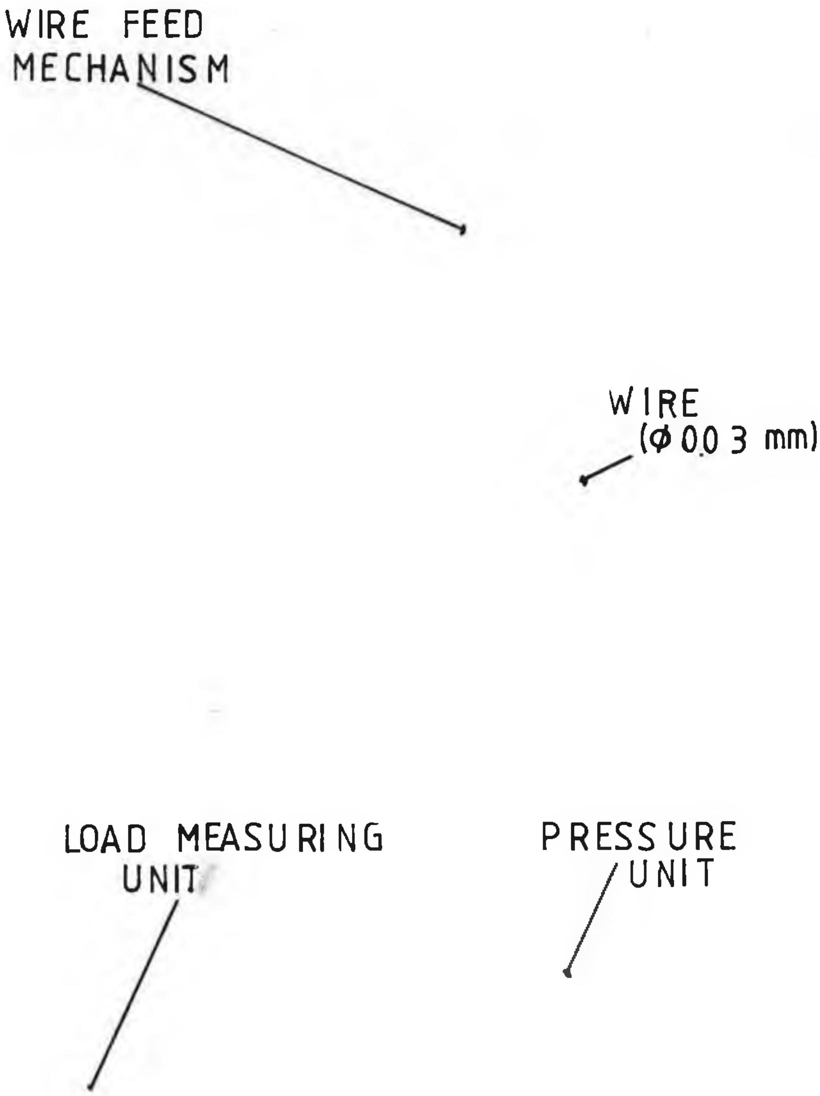

WIRE FEED
MECHANISM
WIRE
(φ 0.03 mm)
LOAD MEASURING
UNIT
PRESSURE
UNIT

PHOTO 3

PHOTO 4

SUPPORT STAND

MELT & PRESSURE
CHAMBERS

THERMOCOUPLE

HEATER BAND

PHOTO 5

REMOTE
TACHOMETER

MOTOR REMOTE
CONTROL UNIT

TEMPERATURE
CONTROLLERS

TWO WAY
SWITCH

VARIAC

PHOTO 6

HEATER BAND CONTROLLERS MAINS SWITCH

BENCH MAINS SWITCH

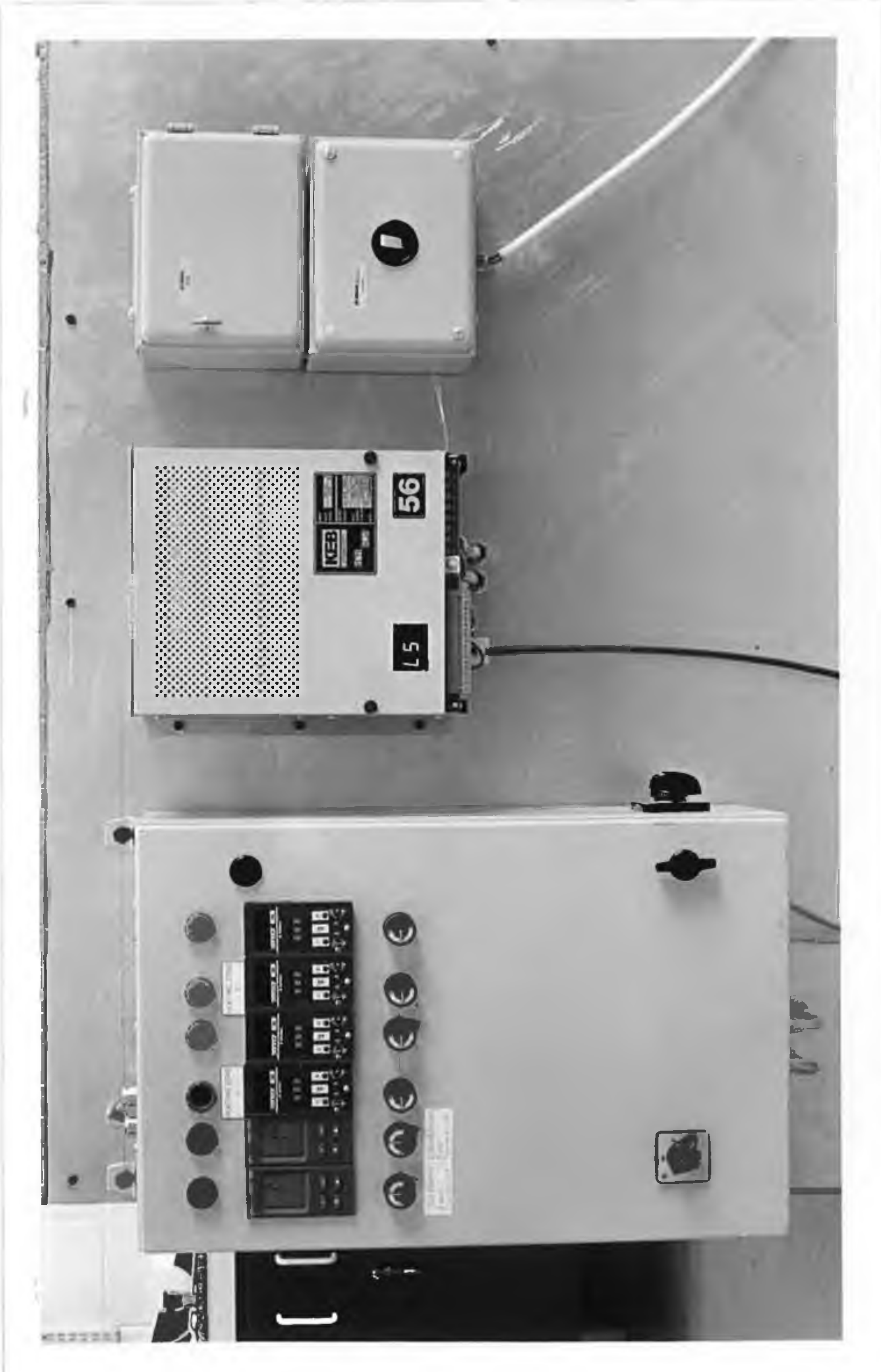

56
L5

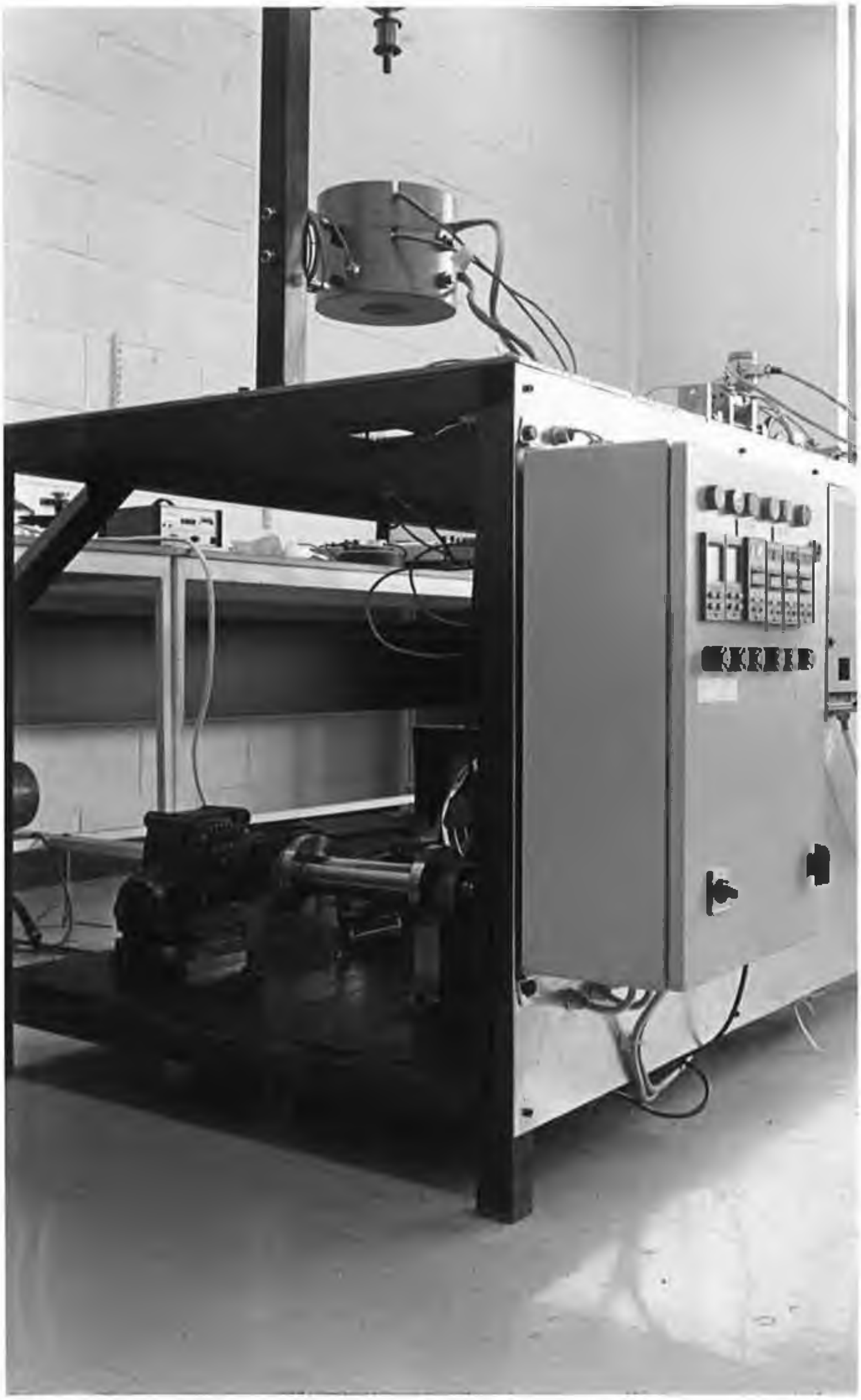
PHOTO 7

A RESEARCHERS EXPERIMENT

PRESSURE UNIT

ELECTRICALS

DRIVE TRAIN



CHAPTER 3

Commissioning and Running Of The Drawing Bench

3.1 Commissioning of the Drawing Bench

The drive train mechanism was tested thoroughly on two separate occasions. After the first series of tests, modifications were made to it as described in section 2.2.3. The second time tests were carried out, the drive train performed satisfactorily with minor vibrations occuring when the bull block was rotating at approximately 1900 RPM and having a peripheral velocity of 15 m/s. The remote tachometer was used to measure the angular velocity of the motor coupling. It was noted that when the bull block was running at slow speeds , the remote tachometer reading varied by up to ± 2 RPM. but when running the motor at speeds over about 600 RPM the tachometer kept on giving a constant reading.

The heater bands were tested to their full limit of 400 ^{o}C, increasing their temperature in increments of 50 ^{o}C. On initial heating, the lubrication which was used when machining the pressure die chamber was evaporated off slowly. The external temperature of the insulation chamber was noted by using the back of the hand. It was carried out at regular intervals in order to preclude the chance of being burnt. On subsequent testing it was noted on one occasion that the heater bands were not being controlled accurately. This problem was caused because the heater bands were plugged into the wrong power supply, hence the heater band temperature was being monitored by the wrong sensor. This was rectified and each plug and socket for the heater band controller were labelled in order to preclude this eventuality occuring again. It was noted that the West 3300 PID controllers needed to be calibrated to each set of heater bands and load facilities in order to achieve the desired control. The configuration used with the heater bands which heated the pressure die chamber is as follows :-

Proportional control	= 2 %
Rate control (Differential)	= 21 sec.
Reset control (Integral)	= 3.5 mins.
Max. Power	= 100 %
Heat Cycle Time	= 16 sec.

Details of how to set up the controllers for any given situation can be seen in the West 3300 controller's manual. Their were no further problems encountered with the heater bands. See Appendix F and References 15 and 16

3.2 General Operations Of The Drawing Bench

This section covers the day to day safe operations of the drawing bench and any heater bands used. This description covers operations from the start to the finish of the experiments.

When checking at the drawing bench, it should be ensured that all switches are in an off position. It should also be checked to see if the motor/gearbox/bull block are in a configuration which will give the range of drawing speeds required for the experiment. If not, the drive-train configuration should be arranged accordingly. The power to the drawing bench should be turned on. The drive-train should be run up to full speed in small steps using the remote speed controller to turn motor on and vary motor speed. This is to ensure that it is running correctly.

Following the set up of the drive-train, turn on the main switch to the heater band controllers and single phase power supply should be turned on. The two-way switch (position 1,2,off) should be kept in an "off" position. When in this position, no power can be applied to the heater bands even though the temperature controllers can monitor the thermocouple inputs. The heater band controllers required for the particular experimental apparatus should be turned on and it should be ensured that each heater band and its associated thermocouple are linked to the one controller. The following should be repeated for the controllers which are going to be used:-

1) Set the "set point" of the controller to 10 $^{\circ}C$ above ambient temperature.

2) Turn the power on to the heater bands (position 1 or 2; in each position 6 heater bands can be controlled by the 6 temperature controllers).

3) Observe the temperature on the controller's display. This should start to rise within one minute.

4) If the temperature does not start to rise within this time, turn off power to the heater bands and check to see which heater band is "on" and which thermocouple is monitoring. Make any necessary alterations.

5) Repeat from 1 above until the heater band temperature stabilises.

The power to the heater band controllers should be turned off and the wire is then threaded through experimental apparatus and attached to the bull block. Next the melt chamber is filled with the desired polymer to be used. The heater band controllers should be turned on and the "set point" of the controllers should be set to the temperature that is required for the experiment, ensuring, however, that the West 3300 temperature controllers' PID settings are configured to the heater band load. The configuration method can be seen in the controller's manual or the college electrician could be asked. A suitable time should be allowed for the heater bands' temperatures to stabilise (Minimum one hour).

The fan should be plugged in for extra motor cooling. Drawing of wire may then commence for the experiment at roughly the desired speed by adjusting the variac frequency using the remote control module. The motor's direction can also be altered with the remote control module. If further motor parameters are to be altered, (ie. acceleration, deceleration, etc.) then the KEB Combivert 56 manual should be consulted. To monitor the motor's running speed turn the Shimpo DT205 needs to be turned on and the remote tachometer needs to be pointed towards the motor coupling which is marked with a piece of reflective tape. It will give a reading of the motor's RPM within three seconds. The linear drawing speed depends on the motor/gearbox/bull block configuration. The RPM to drawing velocity conversion for each bull block set up can be seen below:-

motor/gearbox/small bull block (ϕ 0.06 m)

$$\text{drawing velocity} = \text{RPM} * 324.88 * 10^{-6} \text{ m/s}$$

motor/gearbox/large bull block (ϕ 0.15 m)

$$\text{drawing velocity} = \text{RPM} * 812.2 * 10^{-6} \text{ m/s}$$

motor/small bull block (ϕ 0.06 m)

$$\text{drawing velocity} = \text{RPM} * 3.142 * 10^{-3} \text{ m/s}$$

motor large bull block (ϕ 0.15 m/s)

$$\text{drawing velocity} = \text{RPM} * 7.854 * 10^{-3} \text{ m/s}$$

When a series of experiments have been completed:-

1) Turn power off to heater bands.

2) Set "set point" of temperature controllers to 0°C (this is to ensure that the controllers are in a safe operating mode when the bench is not attended).

3) Turn off individual heater band controllers.

4) Turn off all power to the heater band's control panel

5) Unplug fan used for additional motor cooling.

6) Turn off power to bench after samples have been unwound off the bull block.

3.3 Procedures Specific To This Experimental Research

In addition to the general operations of the drawing bench; the following methods were followed in this research. The melt chamber and pressure die chambers were cleaned out mechanically, using a knife or similar instrument, and assembled together. The wire on which the coating experiments were carried out was threaded through the melt chamber and pressure die chamber using a hooked leader wire with a diameter of 0.9 mm. The wire was then threaded through any inserts and/or die and a retainer plate before being attached to the bull block using sticky tape. This was found by experiment to be the simplest and quickest way of attaching the wire to the bull block, the load being so small. The heater bands were turned on and when they had reached their "set point" for 15 minutes before the experiment was started. Tests were then carried out within 45 minutes as the Lupolen LDPE with a melt flow index (MFI) of 33-39 started to degrade and hence would make the results inconsistent.

There were two different sampling methods used during experimentation:-

1) The wire was drawn onto the bull block at speeds which were recorded and sample tags were attached to

the wire. When experimentation was complete, the wire samples were removed from the bull block for measuring the thickness of the wire coating.

This method worked until wire with a thick coatings (0.1 mm or greater) was tested. With this wire coating the polymer had not completly solidified by the time it had reached the bull block and hence when it was wrapped around the bull block individual strands were stuck together; hence a second method of sampling was used.

2) The wire was drawn onto the bull block and the drawing speed recorded. The sample of wire was then labelled and cut just after the pressure die chamber and just before reaching the bull block. The sample was removed and laid on a side bench. Untested wire was then drawn through the pressure die chamber and attached to the bull block. At the end of a series of experiments the wire on the bull block was discarded. This proved a far more satisfactory arrangement than the first method

At the end of each experiment excessive polymer was removed from the melt chamber and pressure die chamber. The melt chamber, was then removed and cleaned mechanically; having first turned off the power supply and disconnected the thermocouple. The inserts and dies in the pressure die chamber were removed and cleaned in various different ways, which included using emery paper and drill bits for the insert holder. The 0.3 and 0.6 mm inserts were cleaned using 2 methods as follows:-

1) Burning off the polymer using an oxy-acetylene torch;

or 2) A knife was used to clean the surface and some high tensile steel wire was used to "drill" a hole in the inserts. Once a hole was made, wire could be threaded through the insert and the polymer would melt when heated again.

Caution had to be observed as the parts were not allowed to cool down before dismantling . It was found that it was a great deal simpler to clean the experimental apparatus when hot, when the polymer was molten than to clean it out when the polymer was cold and had solidified.

After the experimental apperatus was cleaned the diameter of the wire samples was measured. In measuring the coating thickness, the sample lengths of wire were trimmed so as to remove the wire which was drawn at speeds below the test speed. This length varied depending on the drawing speed. Each sample of wire had its coated thickness measured five times in different places along its length using a micrometer (resolution 0.001 mm) so as to obtain a representative thickness variation along the coated wire. When measuring the wire diameter, the micrometer was turned slowly until its internal overload protection system slipped a ratchet. At this point the measurement was taken. On one point of the wire, the coating was stripped altogether and the wire thickness was measured to see if deformation of the wire had occurred. After measuring each labelled sample, the wire was placed in a labelled sample bag for further reference if necessary.

Chapter 4

Results & Discussion

The initial tests carried out were to see which polymers could be used for the coating of the fine wires. This involved finding out the melting points of the polymers used. The polymers first investigated were Lupolen HDPE (High Density Polyethylene) with a melt flow index (MFI) of about 3 and Polyamide with a similar melt flow index. It was noted that the HDPE started to get tacky at about 140 °C and started giving off vapours at about 215 °C. It was decided that the operating temperature for this polymer would be about 180 °C. The other polymer nylon (polyamide) started to get tacky at about 250 °C and started to give off vapours at about 320 °C. The operating temperature for nylon was decided to be 280 °C. It was noted that at 300 °C, the polymer at the internal edge of the melt chamber had melted but the polymer at the centre had not. This was attributed to the fact that the melt chamber was not covered and due to convection currents, the polymer in the centre of the melt chamber could not reach the melting temperature because of thermal gradients. The problem was overcome when a cover for the melt chamber was installed. The ultra fine wire (ϕ 0.03 mm) was then tested to see if it could be drawn through these viscous polymers. On all occasions the wire broke without moving through the polymer.

At this point it was decided to find a polymer with a viscosity which the 0.03 mm diameter wire could pass through. At one stage golden syrup was used as a test fluid. Its viscostiy was measured using a viscometer and found to be 80 Ns/m^2. The 0.03 mm diameter wire travelled through the syrup and the pressure die chamber as seen in Dwg. No. 50a,Fig. 27 at a speed of 0.048 m/s before breaking. From this it was determined that a polymer with a viscosity of at most, 10 Ns/m^2, was required. Following these results two LDPE (Low Density Polyethylene) types were chosen.

1) Lupolen LDPE with a MFI of between 33-39 and

2) Escoren LDPE with a MFI of about 150.

The next problem which occurred was cleaning the 0.045 mm diameter diamond die. Any time the wire was drawn through the die and the wire broke; the die got blocked with dirt. The method used to clean the die was to leave it in an ultra sonic bath for a period of time. Following this a low suction vacuum pump was used to suck out the dirt. The process was repeated until the die was cleaned. When polyethylene got stuck in the die this process did not work.

Some initial investigations were carried out into coating of wires with diameters of 0.9 and 1.2 mm using Lupolen HDPE. During these investigations the level of the molten polymer stored in the melt chamber was varied. It was noted that the lower the level of the polymer in the melt chamber the faster and the more consistant was the polymer coating. The conclusion drawn from this was that when the polymer level was low in the melt chamber the viscous drag on the wire was reduced. When the cold wire comes in contact with the molten polymer, a small coating thickness is formed which readily picks up more polymer as it passes through the pool of molten polymer. A deeper pool means thicker film of solidified polymer and higher drag force. As a result of this finding the melt chamber was only filled to a level of about 20 mm above the bottom of the melt chamber, so as to facilitate the pre-heating of the wire and reduce the drag force.

It was noted that there was deformation in the tinned copper wire of all diameters tested. This aspect was not investigated thoroughly but should be done in the future. The diameter of the high tensile steel wire varied but not to an extent where it's diameter decreased to a point which was outside two standard deviations of the standard's mean diameter.

In analysing the data which was obtained during experimentation, the following assumptions were made:-

1) The wire used in the experiments had a constant diameter with a small variation in this diameter which was known.

2) The wire's diameter did not decrease. This was in fact not so but in comparison to the variation in the polymer's coating thickness, the assumption is valid

3) The micrometer did not deform the polymer coating. This assumption is questionable as it did deform the polymer coating by up to 15 μm, when the wire was passed through the 0.6 mm insert. This value was determined manually.

The method used to determine the polymer coating thickness involved establishing a standard diameter for each type of wire and noting it's average diameter and standard deviation. These standards were created by taking a minimum of 10 measurements of the wire's diameter over a distance of at least two metres. All results can be seen in Appendix E in a tabular format.

Each of the polymer coated wire test samples had it's diameter measured five times along its length at regular intervals. From this set of results an average wire diameter was calculated along with its standard deviation. A 95% degree of certainty was introduced by saying that all results were within two standard deviations of the mean. The coating thickness and associated error was then obtained by subtracting the average value of the standard wire's diameter from the average diameter for the coated sample wire. The error value was obtained by adding the errors in the standard wire to the errors found in the coated wire. These errors as calculated give a value within two standard deviations of the mean. These values were then divided by two so as to obtain the coating thickness and error margins as seen in Appendix E. For simplicity of understanding these results are shown in graphical form in the figures in this chapter.

The ultra fine wire (ϕ 0.03 mm) was drawn through the final configuration of the pressure die chamber (Fig. 36) while using the Lupolen LDPE, MFI 33-39 as a coating agent. There were two seperate dies used, one was an insert 0.3 mm diameter and the other was a diamond die with a diameter of 0.045 mm. When using these dies, there was a coating on the wire which could be stripped and observed. This coating could not accurately be measured using a micrometer and statistically all that could be shown was that there was a discontinous coating which was not necessariy so. The results can be seen in Appendix E.

As this researcher had no access to surface finish measuring equipment, it was decided that the best method to indicate the variations in the surface finish was to include these variations of the coating thickness in the various graphs of coating thickness versus drawing speed. These variations take the form of vertical error bars and give an indication of coating quality.

Fig. 43 shows the coating thickness of Lupolen LDPE, MFI 33-39 at a temperature of 180 ^{o}C on tinned copper wire with a nominal diameter of 0.17 mm. The die used was 0.25 mm and the pressure die chamber was that as shown in Fig. 36 and the melt chamber was only partially filled. From the graph it can be seen that the coating thickness increases gradually until at a drawing speed of about 35 cm/s it is at a peak. From here it gradually tapers off statistically with the coating thickness quality deteriorating gradually as the drawing speed increases.

Fig. 44 shows the coating thickness of Lupolen LDPE, MFI 33-39 at a temperature of 180 °C on tinned copper wire with a nominal diameter of 0.17 mm. The die used had a bore of 0.25 mm and the pressure die chamber used was that as seen in Fig. 27. The melt chamber was completely filled. The polymer was kept at this set point temperature for a period in excess of one hour. In the graph, two distinct regions can be seen, one below the drawing speed of 20 cm/s and one above this drawing speed. At speeds below 20 cm/s the coating thickness decreases almost linearly with an increase with drawing speed. When drawing at speeds above 20 cm/s the coating thickness is discontinous. This is attributed to the fact that there was very little adhesion of the polymer to the wire and hence the polymer was being drawn. The viscosity of the polymer was such that its maximum flow rate was less than the rate at which the polymer could be strained without breaking. Comparing the results in Fig. 43 and 44 and noting the differences between them it is quite possible that the polymer used in Fig 44 had started to degrade by the end of the experiment.

Fig. 45 shows the coating thickness of Lupolen LDPE, MFI 33-39 at a temperature of 200 °C on tinned copper wire with a nominal diameter of 0.15 mm. The die used was a 0.25 mm insert. In the graph the results appear to be random and do not appear to form any direct relationship between coating thickness and drawing speed. In certain cases even allowing for experimental errors, the points on the graph cannot be linked. In this researcher's view the polymer had degraded and consequently was not of a consestant nature, thus giving these results.

Fig. 46 shows the coating thickness of Lupolen LDPE, MFI 33-39 at a temperature of 180 $^{\circ}$C on tinned copper wire with a nominal diameter of 0.21 mm. The die used was a 0.25 mm die insert. This graph shows the same basic trends as seen in Fig. 43 but the coating thickness is reduced to at most 10 μm. Also the quality of the coating was slightly less than that in Fig. 43. This could be due to surface effects and irregularities in the wire, There were two drawing speeds on the graph where statistically there was no coating.

Fig. 47 shows the coating thickness of Lupolen LDPE, MFI 33-39 at a temperature of 180 $^{\circ}$C on tinned copper wire with a nominal diameter of 0.17 mm. The die insert was a 0.3 mm die . This graph shows the same trends as that seen in Fig. 43 but in a clearer format. The coating thickness quality shows a greater variation in the coating thickness than that seen in Fig. 43. It may be believed that the coating became discontinous for the reasons as described for Fig. 44. The graph shows the same characteristics as seen in Fig. 46 in that within reason the coating becomes discontinous at roughly the same drawing speed.

Fig. 48 shows the coating thickness of Lupolen LDPE, MFI 33-39 at a temperature of 180 ^{o}C on tinned copper wire with a nominal diameter of 0.21 mm. The die insert used had a diameter of 0.3 mm. This graph shows the same trends as previously described in Fig. 46 to 48 but for the discontinous coating found at a drawing speed of 71 cm/s. this could be attributed to two or more factors. One being experimental error but this does not completely explain this because the wire when being drawn at 73 cm/s shows statistically that the coating thickness could be discontinous. Another reason is a phenomenon specific to the drawing bench, ie. minor vibration creating an excessive stress on the polymer which is being drawn, hence the coating becomes discontinous.

Fig. 49 shows the coating thickness of Lupolen LDPE, MFI 33-39 at a temperature of 180 ^{o}C on high tensile steel wire with a nominal diameter of 0.2 mm. The die insert had a diameter of 0.3 mm. This graph shows that the coating thickness of the polymer on high tensile steel wire has the same basic profile of coating thickness versus drawing speed as that seen in Fig. 47 and 48. but the profile is over a greatly reduced range of drawing speeds. This could be due to the fact that the wire initially had an oil based protective coating which was thought to have been removed using a degreasant agent. The short range of drawing speeds could imply that not all the grease was removed from the wire.

Fig. 50 shows the coating thickness of Escoren LDPE, MFI about 150 at a temperature of 145 ^{o}C on tinned copper wire with a nominal diameter of 0.17 mm. The die insert had a diameter of 0.3 mm. This graph shows a distinct characteristic of the polymer coating thickness increasing with increasing drawing speed up to 72 cm/s. From this point on the coating thickness on the wire decreases with an increase in the drawing speed. The quality of the coating deteriorates at speeds above 120 cm/s. At speeds greater than 160 cm/s the coating of the wire becomes discontinous.

Fig. 51 shows the coating thickness of Escoren LDPE, MFI about 150 at a temperature of 145 ^{o}C on tinned copper wire with a nominal diameter of 0.21 mm. The die insert had a diameter of 0.3 mm. The graph shows the same general trends as the graph in Fig. 50 but the coating thickness is less than that which would be expected if there was a linear relation between coating thickness and die clearance. It was noted that the polymer coating becomes discontinous at a slightly slower drawing speed than that seen in Fig. 50.

Fig. 52 shows the coating thickness of Escoren LDPE, MFI about 150 at a temperature of 145 ^{o}C on high tensile steel wire of nominal diameter 0.2mm. On the surface this graph appears to contradict the general trends in the other graphs but on the contrary when the data in the graph is seen in tabular form in Appendix E, it can be seen that the two lowest values for coating thickness at 8 cm/s and 22 cm/s were the first two test samples and this could be put down to experimental error. What cannot be ignored is that the coating thickness does not appear to vary with an increase in drawing speed. If the drawing speed in the graph is exceeded the coating thickness becomes discontinous.

Fig. 53 shows the coating of Lupolen LDPE, MFI 33-39 on tinned copper wire with a nominal diameter of 0.21 mm. The die insert used has a diameter of 0.6 mm. The coating thickness varies as previously described when using inserts with a diamter of 0.3 mm. The coating quality is poor as can be seen from the variations in the coating thickness. There was also one sample of tinned copper wire with a nominal diameter of 0.17mm drawn through this polymer at this temperature. It was drawn at 8 cm/s and had a coating thickness of 0.119 ± 0.039 mm. It is not shown in graphical form because at all other drawing speeds the coating became discontinous.

Fig.54 shows the coating thickness of Escoren LDPE, MFI about 150 at a temperature of 145 ^{o}C on tinned copper wire with a nominal diameter of 0.17 mm. The die insert used had a diameter of 0.6 mm. The graph shows that the coating thickness becomes discontinous at a drawing speed of just below 35 cm/s. The coating thickness does appear, to vary with drawing speed, starting with a thick coating thickness but decreasing as the drawing speed increases.

Fig. 55 shows the coating thickness of Escoren LDPE, MFI about 150 at a temperature of 145 ^{o}C on tinned copper wire whth a nominal diameter of 0.21 mm. The die insert had a diameter of 0.6 mm. The graph shows that the coating thickness gradually increases with speeds up to 35 cm/s and then decreases up to a speed of 50 cm/s. At this speed the coating becomes discontinous.

Fig. 56 shows the variation in coating thickness of Escoren LDPE, MFI about 150 at a temperature of 145 ^{o}C on high tensile steel with with a nominal diameter of 0.2 mm. The die insert used has a diameter of 0.6 mm. The graph shows that the average coating thickness increases with drawing speed at first and then decreases before becoming discontinous at a drawing speed of 30 cm/s. What is most obvious from the graph, is the poor coating quatity being shown in the large error bars.

In overview, the graphs contain complementary information when they are compared against each other. Comparing the temperature differences between the graphs in Fig. 44 and 45 it is evident that a temperature change of the polymer can change the polymers properties which leads to completely different coating results. When experimenting with certain polymers the time which the polymer is kept at an elevated temperature will have a bearing on the the results as well. This information is drawn from the graphs in Fig. 43 and 44. The die configurations were not the same so that there is room for doubt in this conclusion.

A low viscosity or a high melt flow index implies that a polymer coating can be deposited on a wire at a higher drawing speed. This can be seen in Figs. 46-52. This leads to the conclusion that this process requires polymers with a very high melt flow index to be commercially viable.

The coating thickness is related (not directly) to the clearance between the wire and the die. Thus the variation in the coating thickness increases as the clearance between the die and the wire increase. In other words the quality decreases. This could be due to the fact that the ratio between the internal circumference of the die and the circumference of the wire increases. This increases the ratio of the die area to the wire's surface area and also increases drag resistance. Hence the polymer shears on the wire and behaves as a viscous liquid as it is being drawn. This would explain why, as the clearance ratio between the die and the wire increases the maximum drawing speed when the coating remains continous decreases. This can be seen in Figs. 46 to 56.

FIG. 43 COATING THICKNESS ON 0.17 MM TINNED COPPER WIRE.TEMP 180 °C

INSERT DIAMETER 0.25 MM ,POLYMER LUPOLEN LDPE.MFI 33-39

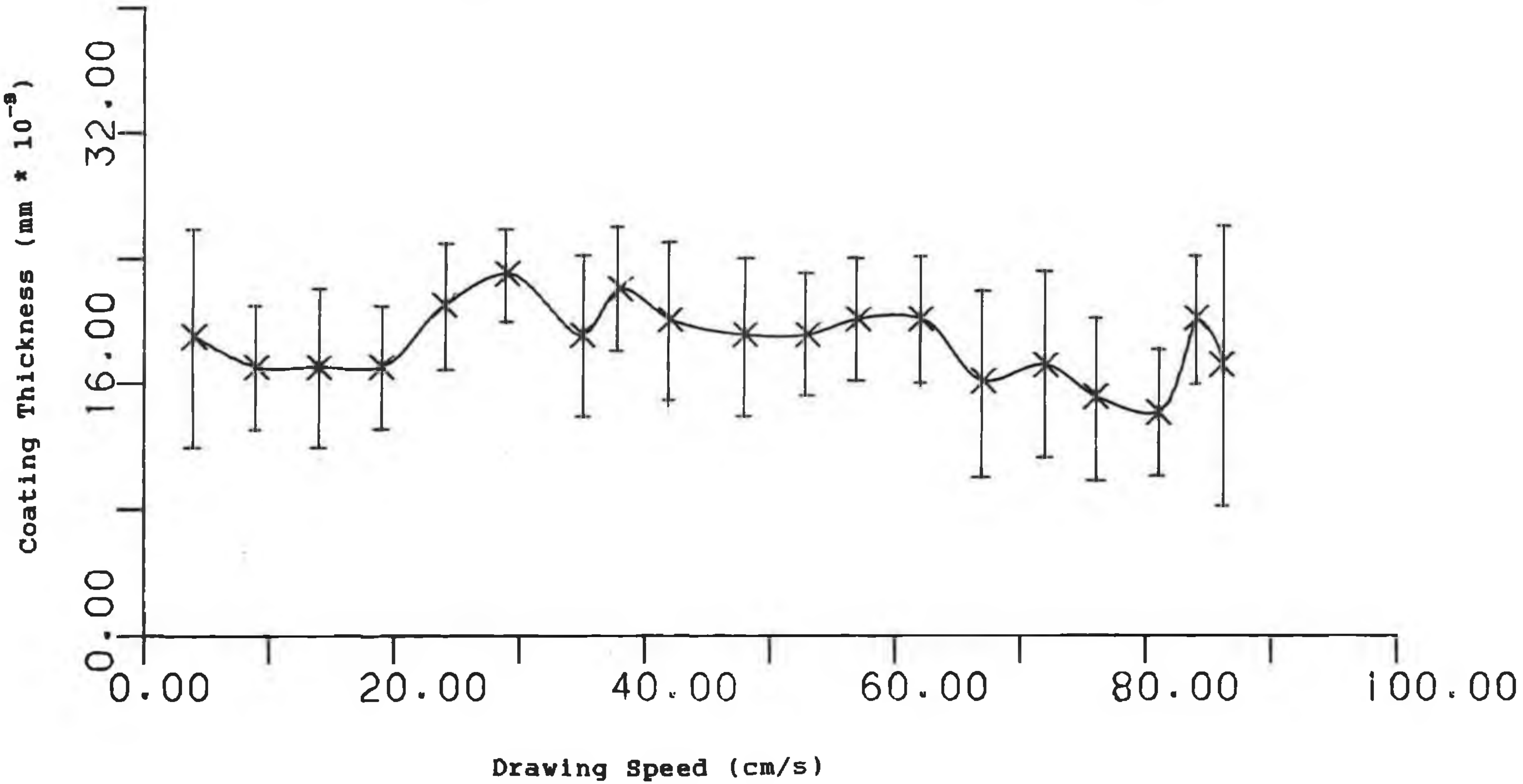


FIG. 44 COATING THICKNESS ON 0.17 MM TINNED COPPER WIRE,TEMP 180 °C
INSERT DIAMETER 0.25 MM ,POLYMER LUPOLEN LDPE,MFI 33-39

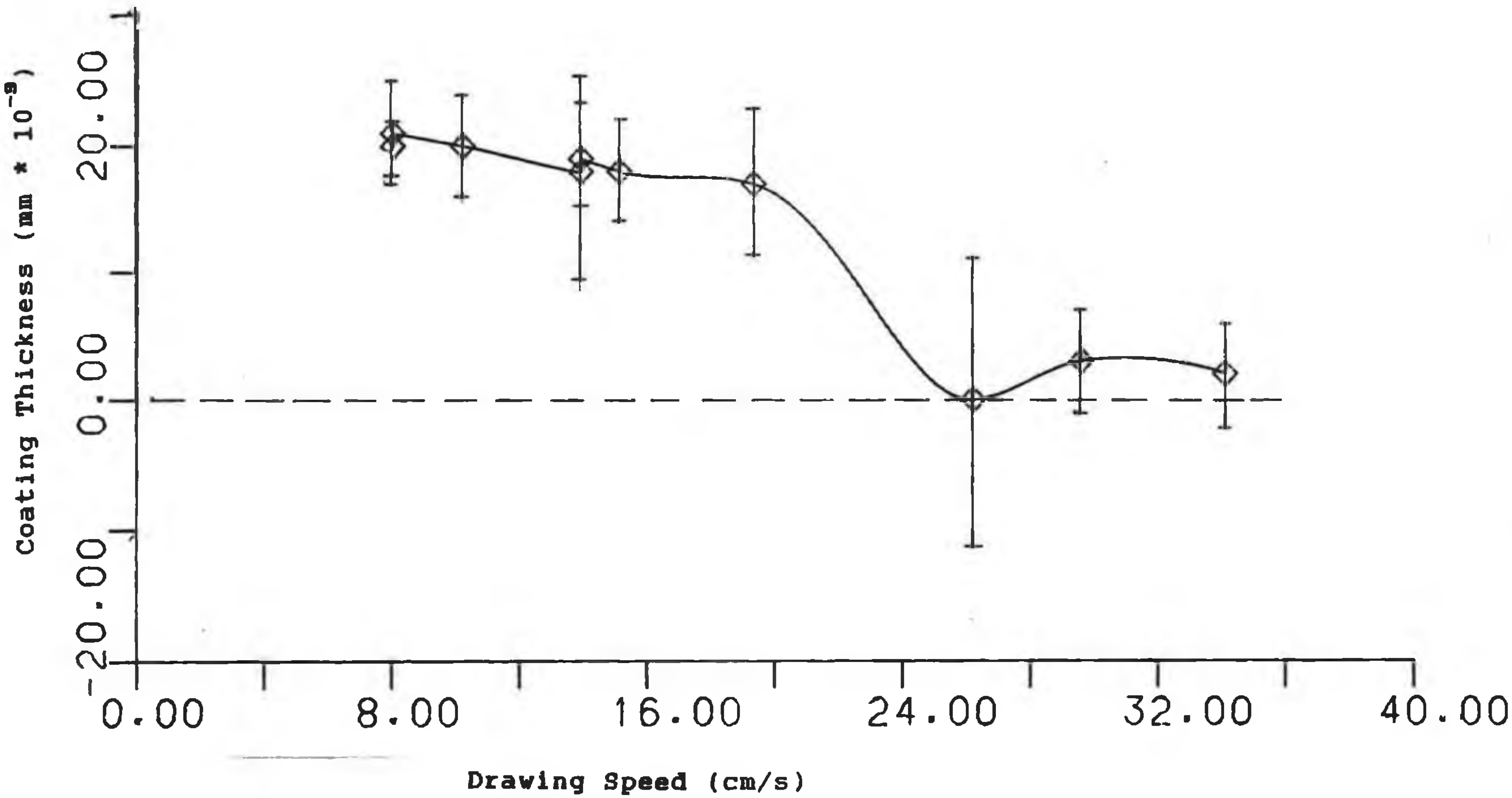


FIG. 45 COATING THICKNESS ON 0.17 MM TINNED COPPER WIRE,TEMP 200 °C
INSERT DIAMETER 0.25 MM ,POLYMER LUPOLEN LDPE,MFI 33-39

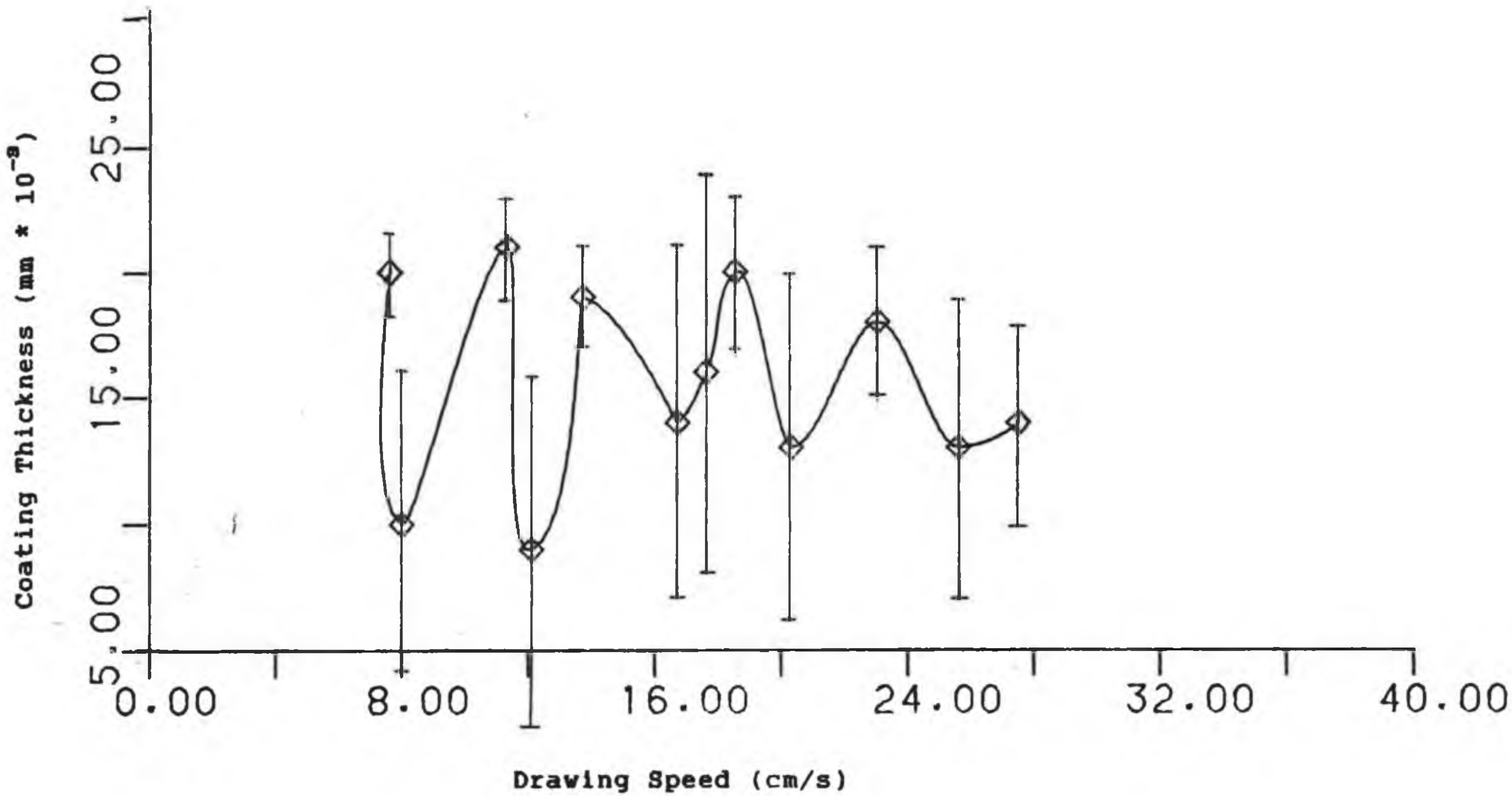


FIG. 46 COATING THICKNESS ON 0.21 MM TINNED COPPER WIRE,TEMP 180 °C
INSERT DIAMETER 0.25 MM ,POLYMER LUPOLEN LDPE,MFI 33-39

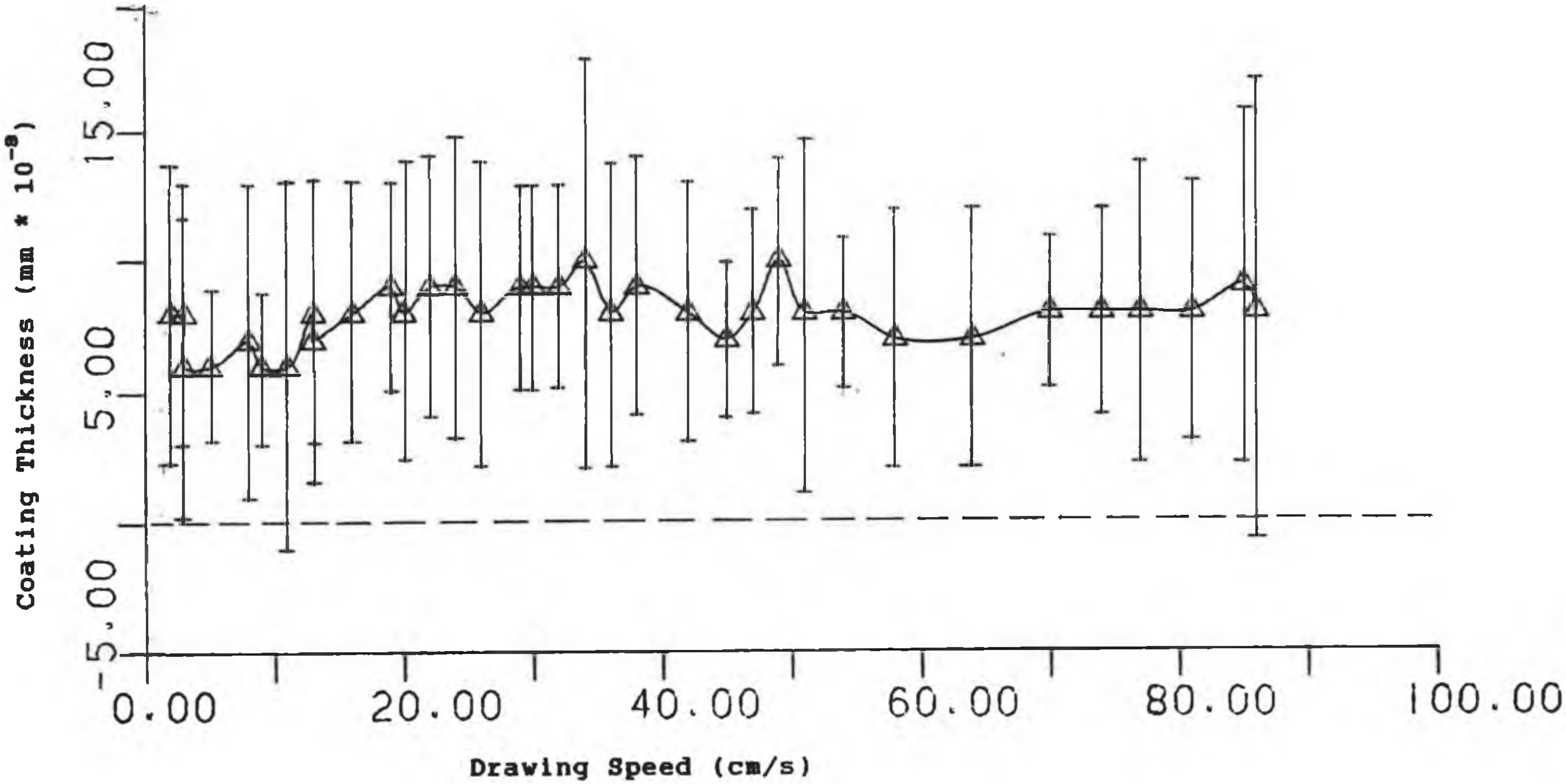


FIG. 47 COATING THICKNESS ON 0.17 MM TINNED COPPER WIRE,TEMP 180 °C
INSERT DIAMETER 0.3 MM ,POLYMER LUPOLEN LDPE,MFI 33-39

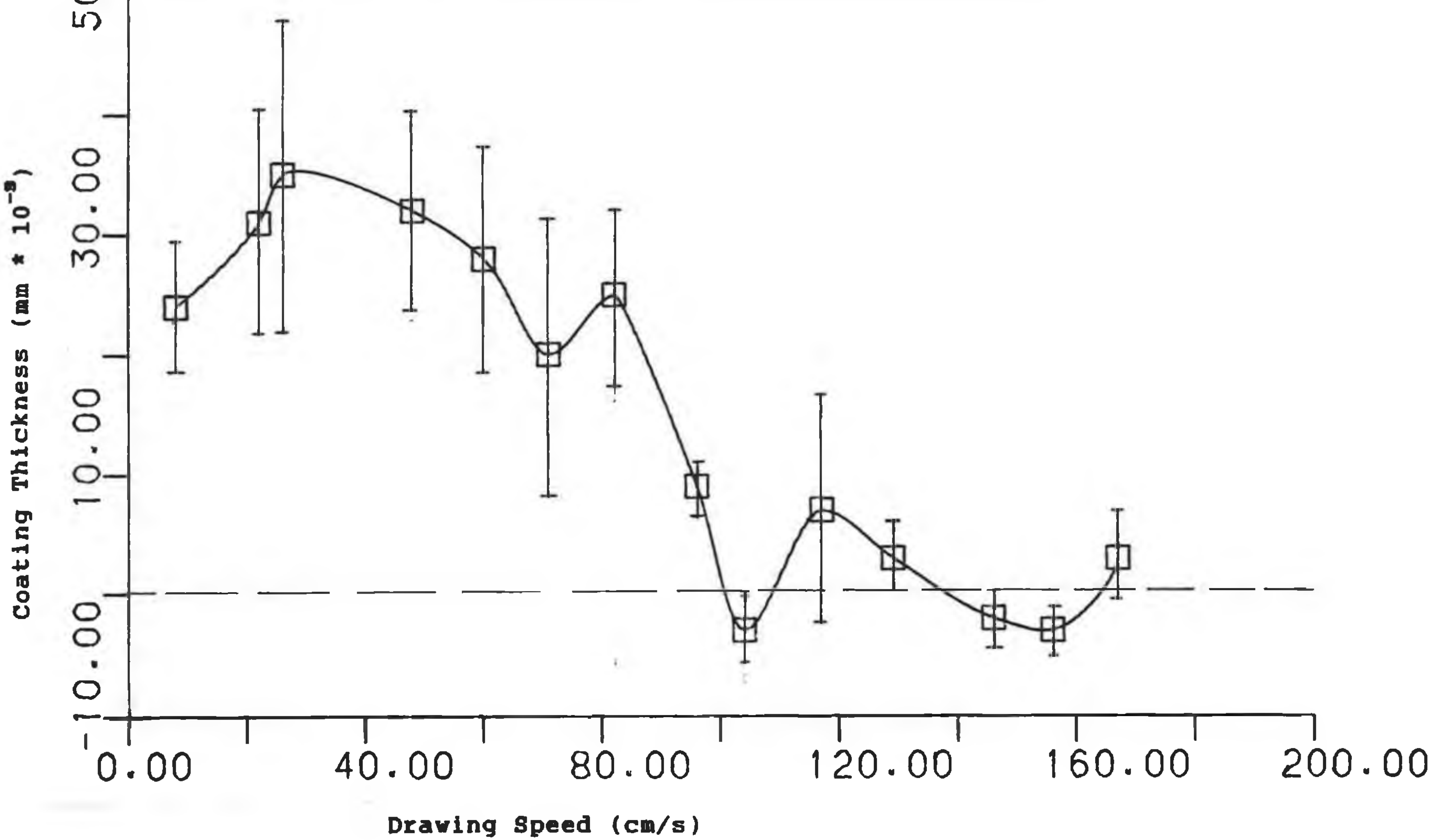


FIG. 48 COATING THICKNESS ON 0.21 MM TINNED COPPER WIRE,TEMP 180 °C
INSERT DIAMETER 0.3 MM ,POLYMER LUPOLEN LDPE,MFI 33-39

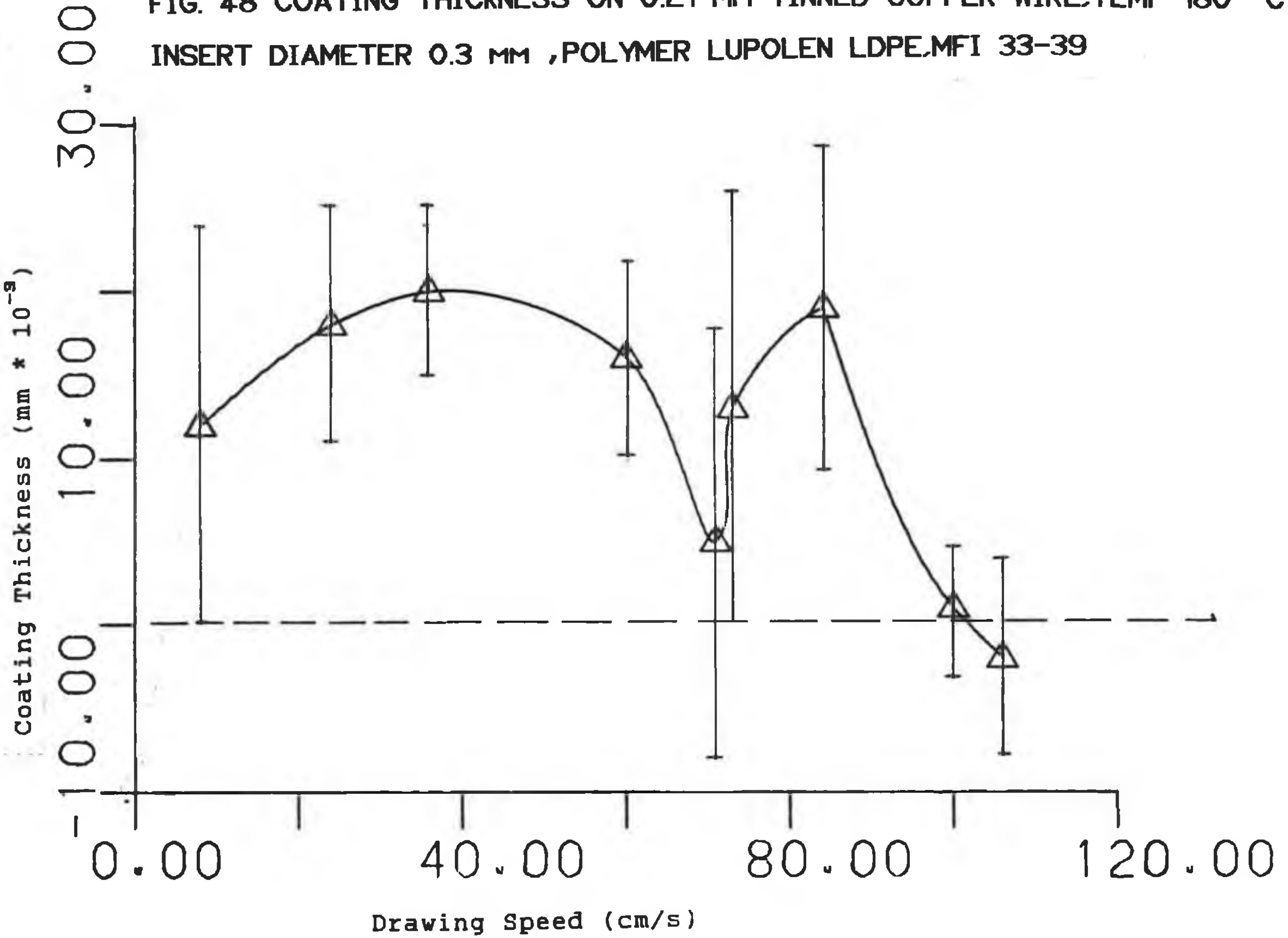


FIG. 49 COATING THICKNESS ON 0.20 MM HIGH TENSILE STEEL,TEMP 180 °C

INSERT DIAMETER 0.3 MM ,POLYMER LUPOLEN LDPE,MFI 33-39

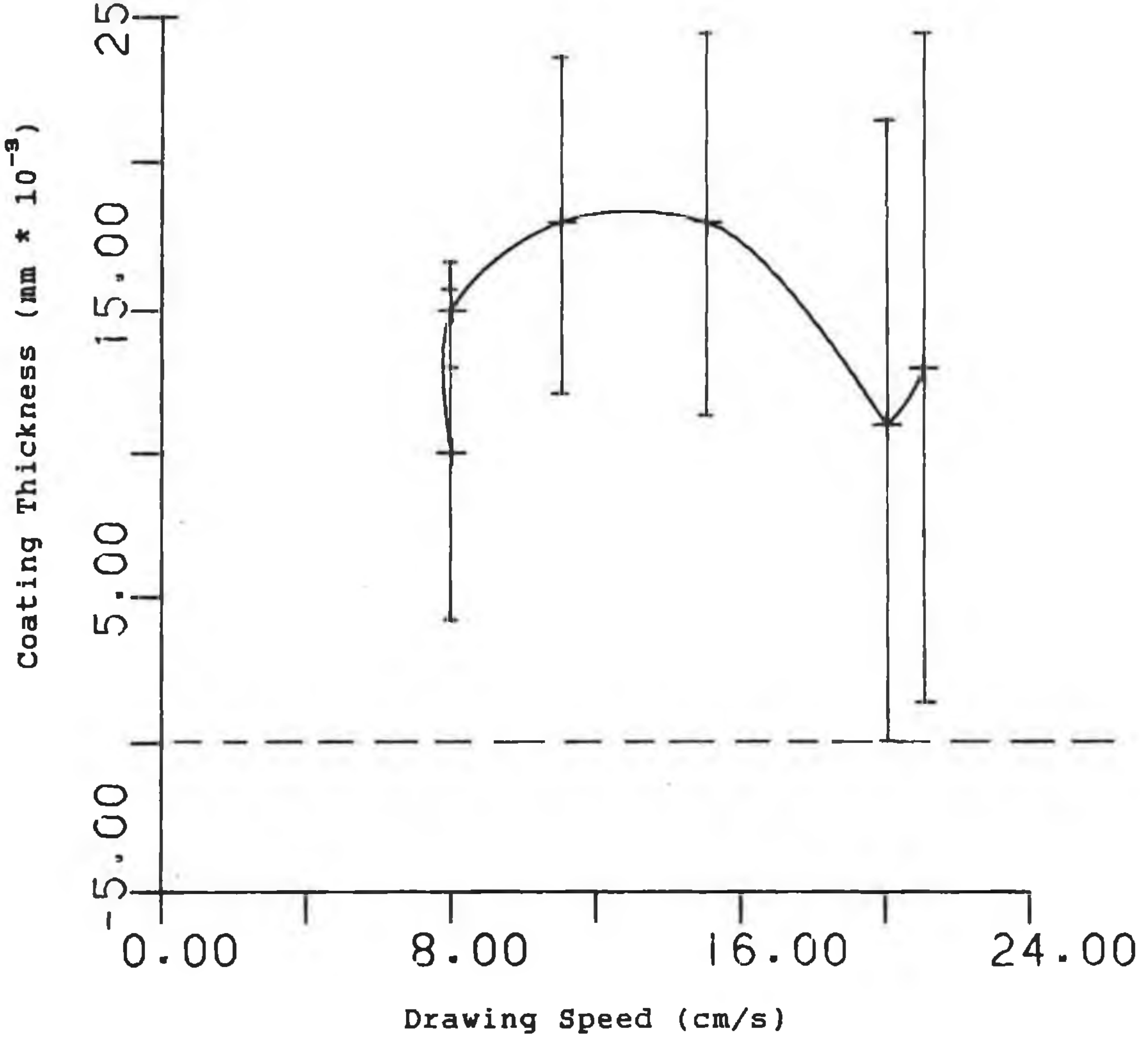


FIG. 50 COATING THICKNESS ON 0.17 MM TINNED COPPER WIRE,TEMP 145 °C

INSERT DIAMETER 0.3 MM ,POLYMER ESCOREN, LDPE,MFI 150

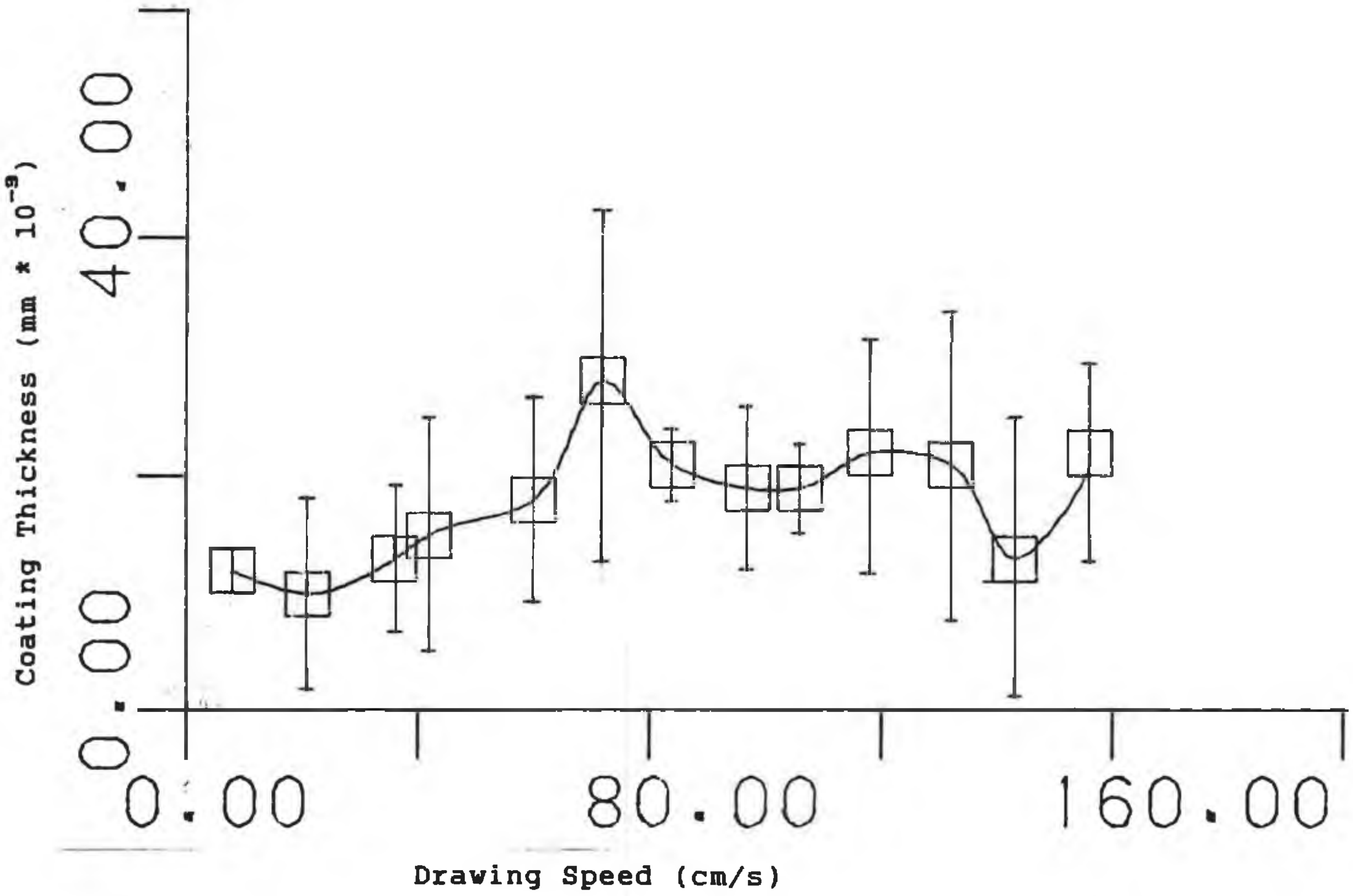


FIG. 51 COATING THICKNESS ON 0.21 MM TINNED COPPER WIRE,TEMP 145 °C
INSERT DIAMETER 0.3 MM ,POLYMER ESCOREN, LDPE,MFI 150

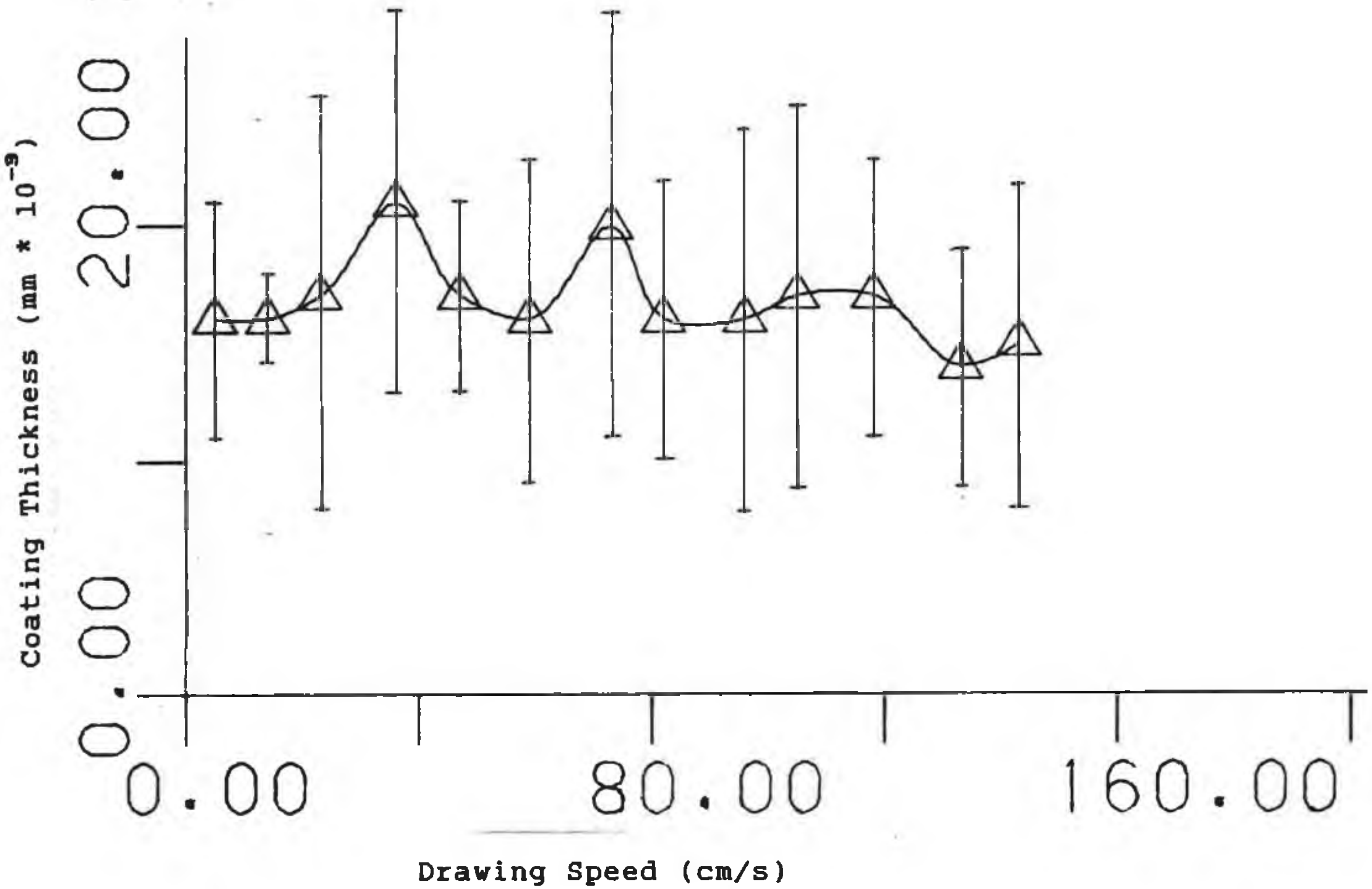


FIG. 52 COATING THICKNESS ON 0.20 MM HIGH TENSILE STEEL,TEMP 145 °C
INSERT DIAMETER 0.3 MM ,POLYMER ESCOREN, LDPE,MFI 150

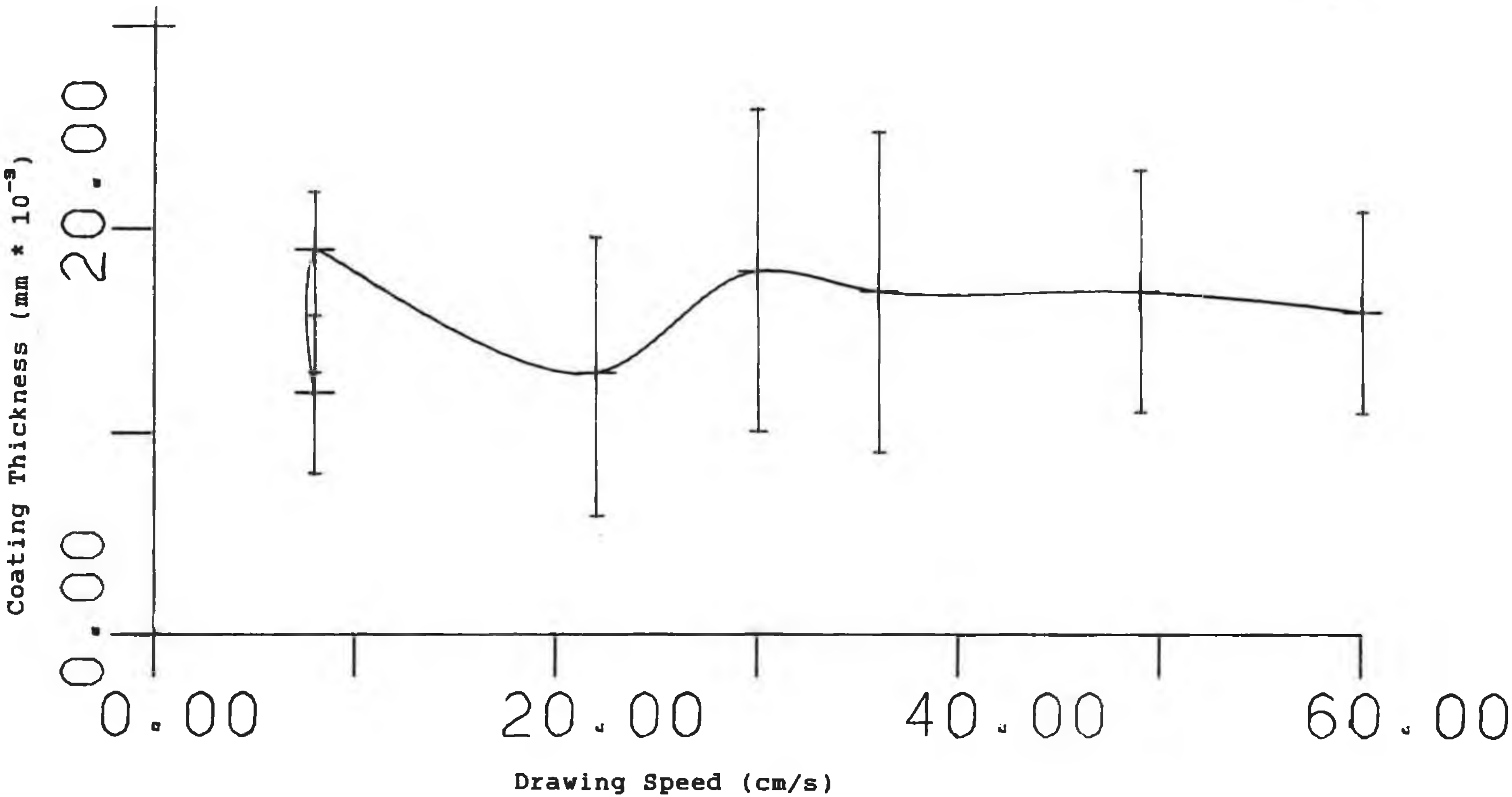


FIG. 53 COATING THICKNESS ON 0.21 MM TINNED COPPER WIRE,TEMP 180 °C
INSERT DIAMETER 0.6 MM ,POLYMER LUPOLEN LDPE,MFI 33-39

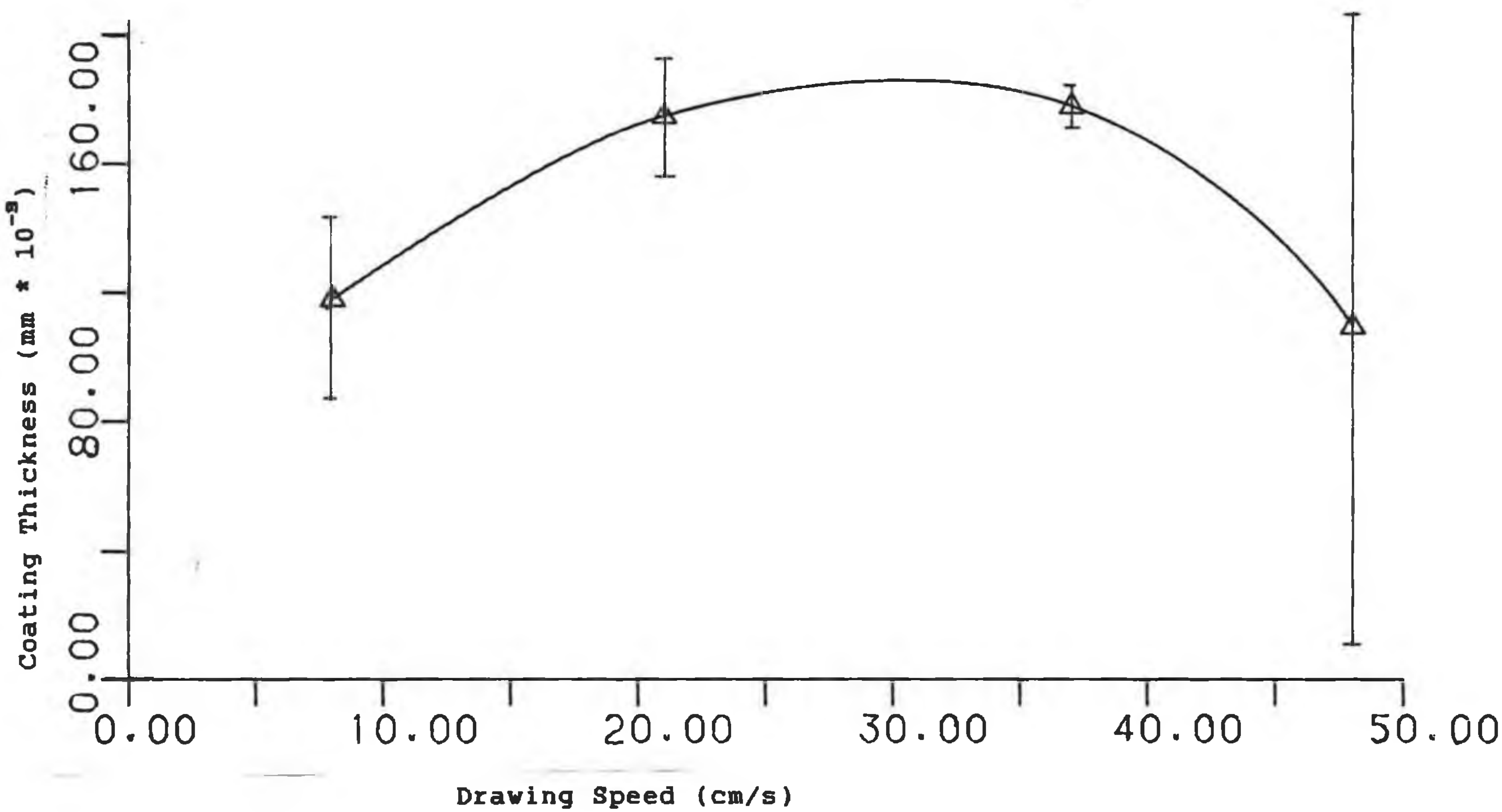


FIG. 54 COATING THICKNESS ON 0.17 MM TINNED COPPER WIRE, TEMP 145 °C

INSERT DIAMETER 0.6 MM, POLYMER ESCOREN, LDPE, MFI 150

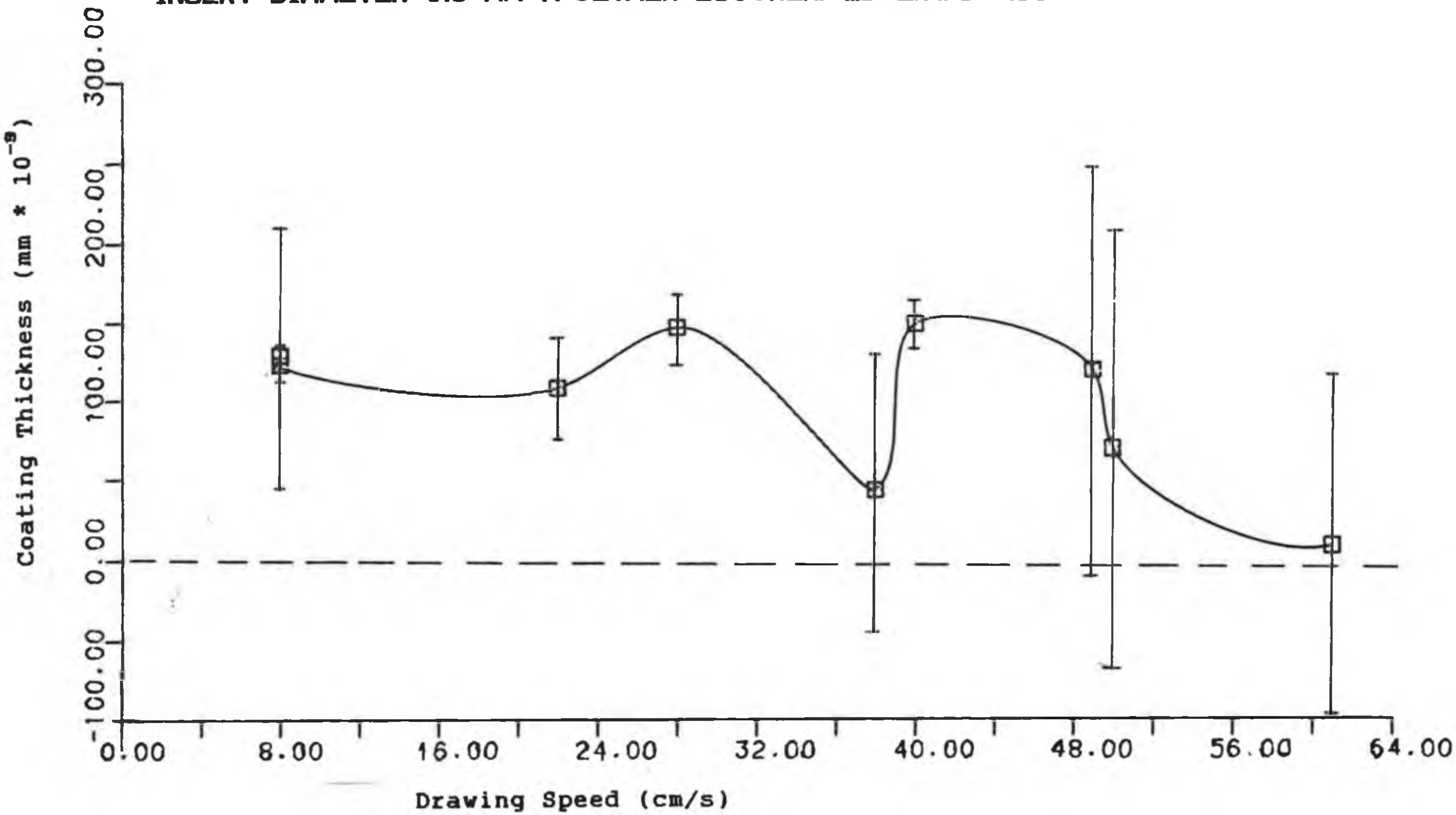
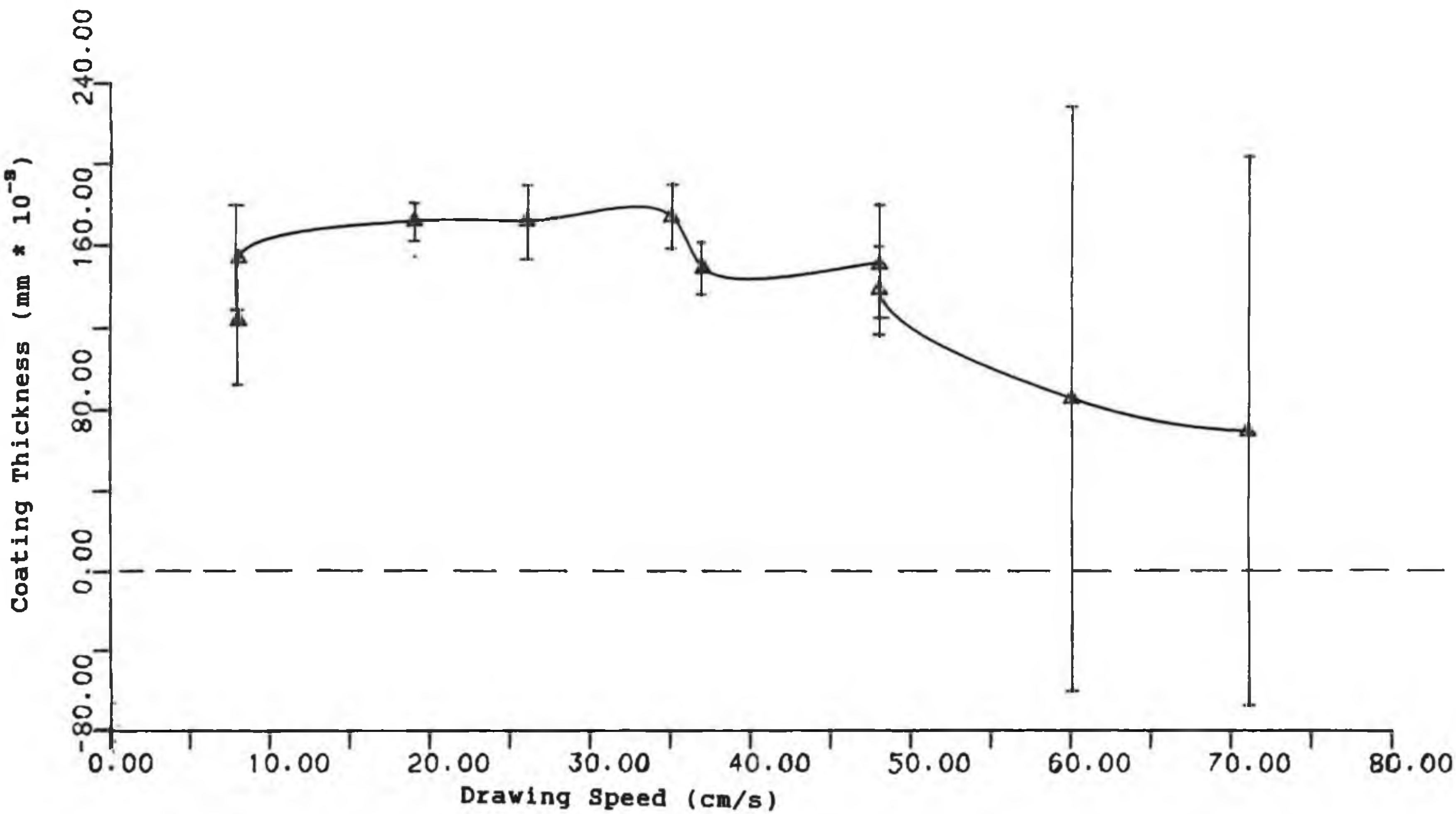


FIG. 55 COATING THICKNESS ON 0.21 MM TINNED COPPER WIRE, TEMP 145 °C

INSERT DIAMETER 0.6 MM , POLYMER ESCOREN, LDPE, MFI 150



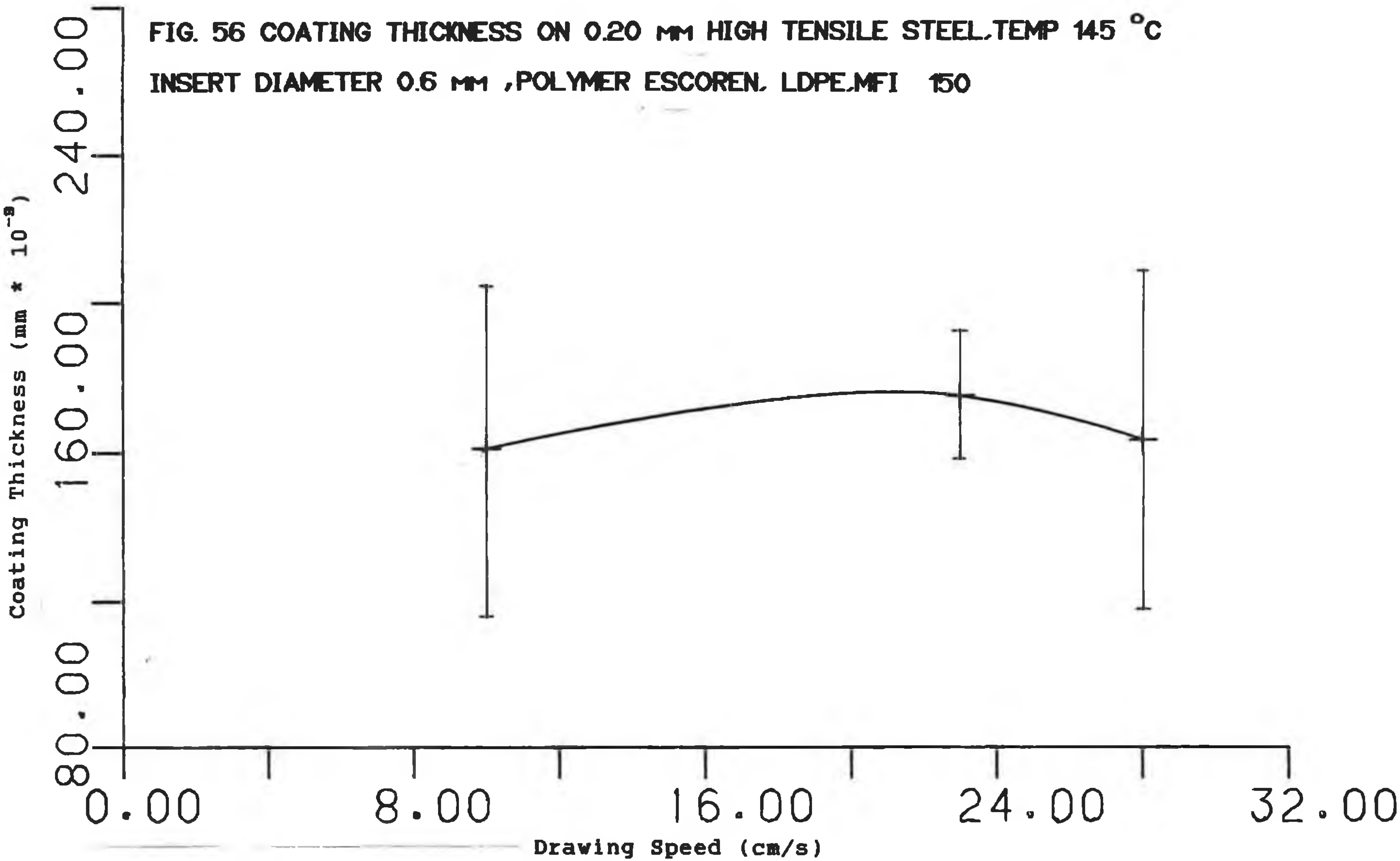


FIG. 56 COATING THICKNESS ON 0.20 MM HIGH TENSILE STEEL,TEMP 145 °C
INSERT DIAMETER 0.6 MM ,POLYMER ESCOREN, LDPE,MFI 150
Coating Thickness (mm * 10⁻³)
80.00
160.00
240.00
0.00
8.00
16.00
24.00
32.00
Drawing Speed (cm/s)

Chapter 5

Conclusions And Suggestions For Furure Research

5.1 Conclusions

A general purpose drawing bench has been designed, manufactured, instrumented and commissioned to facilitate experimental investigation of hydrodynamic coating and/or drawing of fine wires and wire ropes.

Polymer coating experiments have been carried out with fine wire of diameters ranging from 30 μm to 210 μm using a number of different polymers.

It has been established that there is a relationship between the polymer coating thickness and the drawing speed. This relationship depends on a number of parameters including the type of wire being coated, the die to wire clearance ratio along with the melt flow index of the polymer being used. Depending on which of these parameters are being altered, the coating quality can be affected to a greater of lesser extent. There is some relationship between the coating thickness on the wire which depends on the pre-heating of the wire before it reaches the melt chamber. This relationship is not known at present and was not investigated.

At the present moment in time this technique would not be suitable for industrial manufacturing since the coating quality is not constant enough over long periods of time. There is further work that needs to be carried out to refine the process.

5.2 Suggestions For Future Work

It is suggested for the future that a great deal of knowledge be obtained about the rheology of specific polymers being used and their properties at elevated temperatures. This investigation sould include the degrading properties of the polymer over time. This could then lead to a position where a theoretical model for the polymer coating of wire could be developed. From this the dimensions of the pressure die chamber could be optimised by possibly changing the length of the inlet passage before the die and it's bore diameter, the die clearance ratio and finding the optimum temperature for each polymer so that it would not degrade and hence alter the results. The heating of the wire before it passes through the polymer could be investigated. The final result being a coating which could be applied to fine wire at a high drawing speed and produce a quality finish.

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APPENDIX A

Bull Block Calculations

Determination Of Stress In Bolts On Bull Block

Each bull block shell(Dwg. No. 56,Fig. 13) was designed to be held onto two bull block shellholders (Dwg.No.55,Fig. 10) by means of 2*3 bolts with 8 mm. nominal diameter. Each bull block shell is then held onto the Holder Support (Dwg. No. 57,Fig. 9) by means of 3 bolts of 8 mm. nominal diameter. The bolts have a core diameter of 6.466 mm. (according to ISO course thread standards). From materials table 1, the mass of each bull block shell is 2.21 kg. The maximum angular velocity was to be 2800 RPM. (ω = 293 rad/s). Allowing a small F.O.S. , ω was make to be 300 rad/s for design purposes.

The average radius at which the mass of the bull block acts $\approx$ (0.825 + 0.0775)/2 = 0.08 m.

$$\text{Centrapetal acceleration} = \omega^2 * r \qquad (2.1)$$

$$= 300^2 * 0.08$$

$$= 7200 \text{ m/s}^2$$

Radial Force on each bull block shell = m*a

$= 2.21*7200$

$= 15912$ N (2.2)

=> Average force/bolt $= 15912/6$

$= 2652$ N.

Core Area of Bolt $= 32.84\ mm^2$.

Two bolts have tensile load only :-

=> $\sigma = 2652/32.84 = 81\ N/mm^2$.

With the other four bolts the forces were divided up into tensile and shear forces. The load on the bolts was to act at 15 degrees to the shear plane. Hence :-

Shear force $= 2652*\text{Cos } 15^\circ = 2562$ N.

Tensile Force $= 2652*\text{Sin } 15^\circ = 686$ N.

Maximum normal stress $= 686/32.84 = 21\ N/mm^2$.

Maximum shear stress $= 2562/32.84 = 78\ N/mm^2$.

Maximum and minimum principal stresses

$$\sigma_1, \sigma_2 = \frac{1}{2}(\sigma_x + \sigma_y) \pm \frac{1}{2}\sqrt{(\sigma_x - \sigma_y)^2 + 4*\tau^2}$$

$\sigma_y = 0$

$$\sigma_1, \sigma_2 = \frac{1}{2}(21+0) \pm \frac{1}{2}\sqrt{(21-0)^2 + 4*78^2}$$

$$= 10.5 \pm 78.7\ N/mm^2$$

$$= 89.2\ N.mm^2 \text{ or } -68.2\ N/mm^2$$

Principal shear stress τ_{max}

$$= \frac{1}{2}(89.2 - (-68.2))$$

$= 78.7\ N/mm^2$

The yield point for the bolts was taken as 250 N/mm^2, leaving a F.O.S.$\approx$ 3.

Each bull block shell is attached to all four bull block shell holders with at least one bolt. The following design simplifications were made:-

1) Bull block shells carry no stress;

2) All forces in each bull block shell act in the same sense as similar forces in each bull block shell holder which in practice is not so.

This meant that a higher shear stress would be obtained than should actually occur in practice.

Using materials table 1 for the masses of the parts, the total mass for one bull block shell and two bull block shell holders

$= 2.21 + .436*2 = 3.082$ kg.

Average radius at which mass of bull block shell holders acts

$= \frac{1}{2}(0.0615 + 0.0775) = 0.0695$ m.

From equation 2.1, 2.2, and materials table 1, centrapetal force for each bull block shell holder

$= 300^2 * 0.0695 * 0.436$

$- 2727$ N. (2.3)

The total load on the six bolts holding the bull block shell holders to the holder supports is as follows:-

Load due to centrapetal force of bull block shells (eqn. 2.2) + 2* Load due to centrapetal force of bull block shell holders (eqn. 2.3) + Load due to drawing of wire.

$$= 15912 + 2*2727 + 500$$

$$= 21866 \text{ N.}$$

All six bolts are in complete shear and 8 mm. nominal diameter.

$$\tau = 21866/6 * 32.84 = 111 \text{ N/mm}^2.$$

This gives a F.O.S. = 2.25 below the yield point for the bolts. The above calculations assume that the bull block shells and holders are in balance.

Determine Whirling Speed Of The Shaft

In determining the whirling speed of the bull block shaft (Dwg. No.58,Fig. 9), it was necessary to take account of all loads applied to the shaft. The shaft layout in Dwg. No. 58,Fig. 9 was used. The bearings were assumed to simply support the shaft only at their centre and the application of the masses were to act through the mid-points of the holder supports (Dwg. No. 57,Fig. 9). The dimensions used are taken from their mid-points.

Then Dunkerley's empirical formula[14] was used

$$\frac{1}{\omega^2} = \frac{1}{\omega_s^2} + \frac{1}{\omega_1^2} + \frac{1}{\omega_2^2} \ldots$$

Where

ω_s = Natural frequency of transverse vibration of shaft due to beam inertia alone,

ω_1, ω_2 = Natural frequency of transverse vibration for each mass load on the shaft alone, and

ω = Overall whirling speed.

$$\omega_2 = \frac{\pi^2}{l^2}\sqrt{\frac{E*I}{M_l}} \qquad \omega_{1,2} = \sqrt{\frac{3*E*I*l}{m*a^2*b^2}}$$

l = Length of shaft = 0.332m.

I = Second moment of area of shaft = 3.976*E-8 m^4

E = Modulus of Elasticity = 1.94*E11 N/mm^2

M_l = Mass per unit length of shaft = 5.51 kg/m.

a,b = Displacements from end of shaft; a+b = l;

a = 0.025 m.; b = 0.308 m.

m = Mass to be applied to shaft at point.

$\omega_s = \pi^2/(0.332)^2 * \sqrt{(1.94*E11*3.976E-8/5.51}$

= 3350 rad/s.

Total mass applied to the shaft

= Mass of holder supports + Mass of bull block shell holders + mass of bull block shells.

These values come from the materials table 1.

Total mass = 2 * 4.79 + 4 * 0.436 + 2 * 2.21

+ 15.744 kg.

Including mass of bolts, say m $\approx$ 16 kg.

Divide this among the two holder supports

=> Each holder support has an equivalent mass (m) of 8 kg.

Values of a and b are similar because the holders are symetrically mounted on the shaft.

$$\omega_1 = \omega_2 = \sqrt{\frac{3*1.94*E-11*3.976*E-8*0.332}{8 * 0.024^2 * 0.308^2}}$$

$$= 4192 \text{ rad/s.}$$

$$\text{Whirling speed, } \omega = \sqrt{\frac{1}{(1/3350^2 + 2/4192^2)}}$$

$$\omega \approx 2220 \text{ rad/s.}$$

The assumptions made here are that the drawing block was balanced and that the load does not appreciably alter the whirling speed as it is a constant load in one direction. The calculations were carried out for the largest bull block as it would have the greatest mass and give the lowest whirling speed. Also, ignored ind these calculations is the rigidity which the bull block would give to the shaft because of its larger diameter. The bearings used with the drawing block were two SKF SY30 bearings with plummer block housings.

APPENDIX B

Calculations to estimate load on wire at a given drawing speed.

Load for each part = Inertial load due to acceleration

+ Load due to frictional resistance

of bearings.

Determine load for wire reel mechanism (Dwg. No. 102)

$J = \frac{1}{2}*M*r^2$ $m = \pi*r^2*l*\rho$

$= \rho*\pi*l*d^4$ (A1)

r = radius (mm) l = length (mm)

d = diameter (mm) $\rho = 7.8*E-6\ kg/mm^3$

Density obtained from Uddeholm material specifications

J for Dwg. No.76,Fig. 24b

$J = (20^4*2+14^4*15+16.4^4*60+15^4*15+14^4*25)*7.66*e-7$

$= 5.85\ kg/mm^2$

J for Dwg. No.79

$J = 7.66*E-7*6*12^4 \approx 0.1\ kgmm^2$

J for wire drum (reel for holding uncoated wire)

$J = m*k^2$ m = mass (kg)

k = radius of gyration

$m \approx 0.15$ kg. k (guestimate) $\approx$ 15 mm

$J = 0.15*15^2 = 33.75\ kgmm^2$

Total polar moment of inertia for wire reel mechanism

$J = 33.75 + 5.85 + 0.1 = 39.7\ kgmm^2$

$\approx 4*E-5\ kgm^2$ if moment of inertia due to the bearings is included.

Load on wire due to inertial acceleration of wire reel

$= 4*E-5 * v/(0.016^2*t) = 0.15*v/t.$

Calculating load due to bearings for wire reel mechanism.

$M = 10^{-7}*f_o*(\nu*n)^{2/3}*d_m^3$

Formula from SKF Bearing catalogue 3200/IE,p46

ν = kinematic viscosity (mm^2/s) = 20 (guestimate) mm^2/s

n = bearing speed r/min = 60*f

f_o = factor depending on bearing = 1.5 for deep groove ball bearings.

M = moment caused by resistance of bearings (Nmm)

d_m = mean bearing diameter [=0.5(d+D] (mm)

d = internal diameter of bearing

D = external diameter of the bearing.

ω = angular velocity, rad/s

r = radius at which wire acts, mm

v = velocity, m/s

f = rotating speed, rev/s = $\omega/2\pi$

$v = \omega*r*10^{-3}$

$v = 2*\pi*f*r*10^{-3}$

$v = (2*\pi*n*r*10^{-3})/60$

$n = 60*v(2*\pi*r*10^{-3}$, rev/min.

$$M = 10^{-7}*1.5*\left[\frac{20*60*v}{2\pi*r*10^{-3}}\right]$$

$$= 4.976*E{-}4*\left(\frac{v}{f}\right)^{2/3}*d_m^3$$

=> load on wire = $4.975*E{-}4*v^{2/3}*d_m*r^{-5/3}$. (A2)

For the two bearings used with the wire drum

(SKF 6002-2Z, SKF 6003-2Z)

d_m = 23.5 and 26 mm. respectively.

Load on wire at radius of 16 mm from centre of shaft

From equation A2

Load on wire due to wire reel bearings

$= 4.975*E{-}4*16^{-5/3}*(23.5^3*26^3)^{2/3}$

$= 0.149*v^{2/3}$ N.

Total wire load due to wire reel

$= 0.149*v^{2/3}+0.156*v/t$. (A3)

Determine load due to pulley mechanism (Dwg. NO.103)

Using equation A1.

J for Dwg. No.81,Fig. 23a

$J = 7.66*E{-}7*15*(22^4-10.5^4) = 2.55*E{-}6$ kgm^2

J for Dwg. No.82,Fig 23a

$J = 7.66*e{-}7*(2*14^4+100*E4) = 0.824*E{-}6$ kgm^2.

J for Dwg. No.83,Fig 23a

$J= 7.66*E{-}7*25*(22^4\ 10^4) = 4.26*E{-}6$

Calculating Polar moment of Inertia for pulley (Fenner

031 Z 0241), no technical information available about this pulley.

Total mass of pulley = 1.93 kg (weighed)

Assumed $\rho \approx 7.8*E-6\ kg/mm^3$

See Fig.B1 for rough dimensions.

Mass for centre of pulley plus taper lock bushing.

$= \pi*(44.5^2\ 11^2)*27*7.8*E-6 = 1.23$ kg.

$k^2=(r_1+r_2)/2$ k = radius of gyration

r_1, r_2 = internal and external radii.

$k^2=(44.5^2+11^2)/2 = 1050\ mm^2$

Mass of Web = $7.8*E-6*6*(74.5^2-44.5^2)*\pi = 0.525$ kg

$k^2=(74.5^2+44.5^2)/2 = 3765\ mm^2$

Outer section of pulley = 1.93 -1.23-0.525 = 0.175 kg.

$k^2 \approx (92.5^2+74.5^2)/2 = 7053\ mm^2$

Assuming mass is evenly distributed over radius,

J for Pulley = 1.23*1050 + 0.525*3765 + 0.175*7053

$= 4.5*E-3\ kgm^2$.

Total Moment of Inertia for Pulley Mechanism, J_{tot}

= 2.55*E-6 + 0.824*E-6 + 4.26*E-6 +4.5*E-3

$= 4.51*E-3\ kgm^2$.

Load on wire is at a distance of 81 mm. from centre of pulley shaft.

=> Load on wire due to inertial acceleration of pulley

$= 4.51*E-3*v/0.081^2*t = 0.687*v/t$ N.

The two bearings used on the pulley are SKF 6000-2Z.

Using equation A2, $d_m = 18$ mm.

Load applied to wire due to moment of bearings

$= 4975*E-4*18^3*v^{2/3}/18^{5/3}$

$= 1.913*E-3*v^{2/3}$ N.

Therefore total load on wire due to pulley

$= 0.687*v/t + 1.913*E-3*v^{2/3}$ N. (A4)

Total load on wire due to feed mechanism

= equation A3 + equation A4

$= 0.149*v^{2/3}+0.156*v/t + 0.687*v/t+1.913*E-3*v^{2/3}$

$= 0.15*v^{2/3} + 0.843*v/t$ N. (A5)

Using equation A5 it was calculated that wire could not be drawn at speeds greater than ≈ 1.5 m/s, given that the breaking load of the wire was 0.4 N. However in practice a maximum drawing speed of 0.12 m/s was achieved. The difference being attributed to inertia and load resis tances which were not accurately defined in calculations.

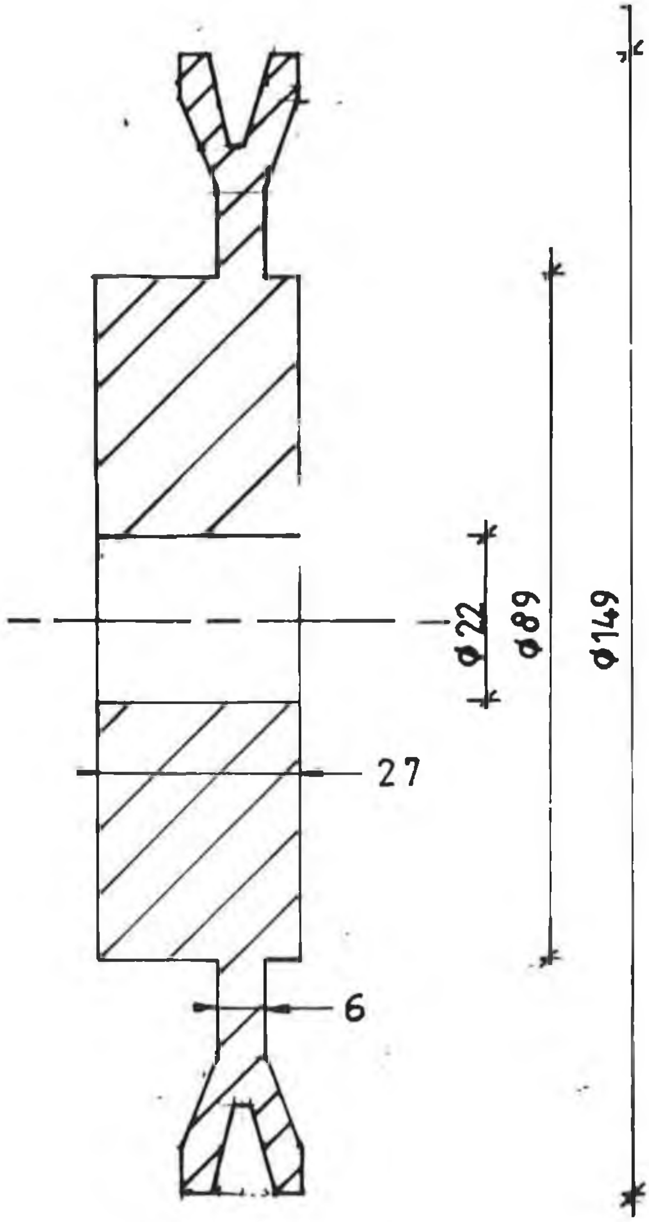


FIG. B-1 CROSS SECTION OF PULLEY

APPENDIX C

Heat Loss Calculations For Pressure Die Unit

This was divided into three surfaces :-

1) Top surface

2) Bottom surface

3) Cylindrical surface.

There was assumed to be no insulation around the top and bottom surfaces and the surface to air heat transfer co-efficient, h=13 W/m^2. Heat loss from both top and bottom surfaces was assumed constant, even though heat losses from the bottom would be less, due to the fact that heat rises. The design parameters were as follows :-

1) Ambient temperature = 20 $^{\circ}C$

2) Maximum temperature for pressure chamber = $400^{\circ}C$

Using Fourier's Law

$Q = U*A*\Delta t$ (Watts) (C1)

Q = Heat loss in Watts

U = Thermal Conductivity ($W/m^{2\circ}C$)

A = Area (m^2)

Δt = Temperature difference between surface edges ($^{\circ}C$)

HEAT LOSS AT TOP SURFACE

$A = 0.04^2*\pi = 5.1*E-3\ m^2$

$\Delta t = 400-20 = 380\ ^{\circ}C$

$U = 13\ W/m^2$

Q = 13*5.18*E-E-3*380 = 26 Watts heat loss

HEAT LOSS AT BOTTOM SURFACE

$A = 0.035^2*\pi = 3.85*E-3\ m^2$

$\Delta t = 400-20 = 380\ ^{\circ}C$

$U = 13\ W/m^2$

Q = 13*3.85*E-3*380 = 19 Watts heat loss.

HEAT LOSS THROUGH VERTICAL WALL OF CHAMBER

Assumptions:-

1) Thickness of heater bands ignored for heat loss.

2) Insulation is evenly distributed in housing.

3) There are no end effects at top and bottom of insulation, ie.,heat only travels radially.

For heat loss through a cylindrical tube:-

$Q' = u'*(t_2-t_1)$

Q' = Heat loss per unit length, Watts/metre.

U' = heat transfer co-efficient per unit length of cylinder.

$\Delta t = t_2-t_1$ = temperature difference between internal and external surfaces.

For multiple layers of material with different heat transfer co-efficients :-

$$\frac{1}{U'} = \frac{1}{2*\pi*r_o*h_a} + \sum_{i=1}^{n} \ln(r_i/r_{i-1})/2*\pi*k_i + \frac{1}{2*\pi*r_n*h_b}$$

h_a, h_b = surface heat transfer co-efficients, $W/m^{2\circ}C$.

k_i = thermal conductivity of material, $W/m^{\circ}C$

r_i, r_{i-1} = radii at which junctions between material occurs.

The design layout of Pressure die, insulation and insulation housing can be seen in Dwg. No. 100,Fig. 25.

Insulation thickness = 0.57 mm.

r_2 = 0.097 m. r_1 = 0.04 m.

$k \approx 0.096\ W/m^{\circ}C$.

Insulation housing thickness = 0.003 m.

r_3 = 0.1 m r_2 = 0.097 m.

$k \approx 29.5\ W/m^{\circ}C$.

Surface heat transfer co-efficient metal to air = 13 $W/m^{2\circ}C$

$$\frac{1}{U'} = \frac{1}{2*\pi*0.1*13} + \ln\left(\frac{0.097}{0.04}\right)/2*\pi*0.096 + \ln\left(\frac{0.1}{0.097}\right)/2*\pi*29.5$$

$$= 1.59\ m^{\circ}C/W$$

Heat loss Q = 0.628*380*0.165 ≈ 40 Watts

To find vertical external surface temperature of insulation housing using equation C1:-

t_2 = 20 $^{\circ}C$ t_1 = ?

$h = 13\ W/m^{2\circ}C$ $A = 2*\pi*0.1*0.165 = 0.104\ m^2$

$t_1 = Q/(h*A) + t_2$

$t_1 = 40/(13*0.104) + 20$

$\approx 50\ ^{\circ}C$

=> external surface temperature of insulation housing $\approx 50\ ^{\circ}C$

Total estimated heat loss from pressure die chamber $\approx 50 + 19 + 26 = 95$ Watts.

Total output from heater bands ≈ 1000 Watts.

This leaves an adequate difference between supplied heat and heat loss from chamber to allow for a reasonable short period of heating up time.

Appendix D

The load cell dimensions were calculated as follows using simple Bending Theory :-

$$\frac{\sigma}{y} = \frac{M}{I} \qquad\qquad y = \frac{d}{2}$$

$I = \frac{bd^3}{12}$ for a bar with a rectangular cross-section

$M = F.x$ x = Maximum displacement along the beam.

F = Maximum force to be applied to the beam

M = Applied moment

Since the load cell consists of the equivalent of two parallel beams, the maximum force to be applied to the load measuring device is twice that which can be applied to a single beam.

$$F_{max} = \frac{b.d^3.2}{d.12.2} = \frac{\sigma.b.d^2}{12.x}$$

Let x = 50 mm = length of beam

b = 25 mm.

σ = 250 N/mm^2, this leaves a F.O.S. of about 2.

below the yield point of the material UHB11 which has a yield point of 540 N/mm^2.

$$\Rightarrow F_{max} = \frac{250*25*d^2}{12*50} = 10.4*d^2$$

The load applied to the load measuring device

= Static load due to weight of pressure die unit

+Load due to the drawing of the wire.

The static load is due to the weight of the pressure die chamber plus the polymer contained within

= 9.81 * (Total mass of pressure die unit + polymer)

Total mass of Pressure die chamber	= 9.45 kg.
Total mass of Heater bands	= 1.05 kg.
Total mass of polymer	$\approx$ 0.10 kg.
Total mass	= 10.60 kg.

Allowing a small factor for error in measurements, say 11 kg.

=> Static load applied to load cell = 11*9.81 =107.9 N.

Let maximum dynamic load to be applied to load measuring device = 200 N.

=> Total load to be applied to load measuring device

= 308 N.

Therefore depth of bars in cell = $\sqrt{\dfrac{308}{10.4}}$ = 5.44 mm.

Let members = 6 mm. thick

= Total load that can be applied to load measuring device = 375 Newtons.

APPENDIX E

This Appendix contains the experimental results of this research, listed in a tabular form plus the mesured standards which were created.

The key to the abbreviations used in the results table is shown balow:-

Polymer A = Lumpolen LDPE with a MFI of 33 to 39

Polymer B = Escoren LDPE with a MFI of about 150

Drive train configurations:-

SBB+GB = Motor/Gearbox/Small Bull Block

LBB+GB = Motor/Gearbox/Large Bull Block

Sample Number Coding:-

The first two digits reading from the left hand side were used to spedify the wire used as shown below:-

17 = Tinned copper wire with a nominal diameter of 0.17 mm.

20 = High tensile steel wire with a nominal diameter of 0.20 mm.

21 = Tinned copper wire with a nominal diameter of 0.21 mm.

03 = EN58A steel wire with nominal diameter of 0.03 mm.

The third and fourth digits reading from the left were used to identify the die insert used in the experiment:-

25 = die insert with 0.25 mm diameter.

30 = die insert with 0.30 mm diameter.

60 = die insert with 0.60 mm diameter.

The fifth and sixth digits reading from the left were used to identify the number of the particular experiment. The letter on the right hand side of the sample number was used to identify the polymer being used in the experiment as explained earlier.

Tables Of Result And Standards Are As Seen Below:-

STANDARDS USED FOR MEARURING THE WIRE'S DIAMETER

TINNED COPPER WIRE WITH NOMINAL DIAMETER OF 0.152 MM
MEASURED DIAMETER (MM)

.162	.164	.162	.164	.165	.164	.167
.164	.164	.166	.164	.165	.164	.163

AVERAGE DIAMETER	.164	MM
STANDARD DEVIATION	.001	MM

TINNED COPPER WIRE WITH NOMINAL DIAMETER OF 0.213 MM.
MEASURED DIAMETER (MM)

.208	.208	.213	.208	.208	.211	.209
.207	.209	.211	.211	.207	.208	.209
.207						

AVERAGE DIAMETER	.209	MM
STANDARD DEVIATION	.002	MM

HIGH TENSILE STEEL WITH NOMIMAL DIAMETER OF 0.2 MM
MEASURED DIAMETER (MM)

.207	.206	.206	.207	.206	.205	.206
.208	.207	.205				

AVERAGE DIAMETER	.206	MM
STANDARD DEVIATION	.001	MM

Configuration SBB+GB POLMER A . TEMP 180 C INSERT 0.045 MM

WIRE 0.03 MM DIAMETER EN58A STEEL WIRE

SAMPLE NO.	RPM	DRAWING SPEED (m/s)	MEASUREMMEASUREMENTES OF WIRE DIAMETER (mm)					AVERAGE DIAMETER OF COATED WIRE (mm)	STANDARD DEVIATION	DIA. OF STRIPPED WIRE (mm)	COATING THICKNESS (mm*E-3)
30.1	100	.03	.031	.030	.031	.031	.031	.031	.000	.030	0.0 ± 0.0
30.2	126	.04	.031	.031	.031	.031	.032	.031	.000	.031	0.0 ± 0.0
30.3	251	.08	.031	.033	.032	.032	.031	.032	.001	.029	1 ± 1
30.4	284	.09	.032	.031	.031	.031	.031	.031	.000	.029	0.0 ± 0.0
30.5	334	.11	.032	.032	.032	.032	.032	.032	.000	.030	0.0 ± 0.0
30.6	SAMPLE BROKE ON ACCELERATION										
30.7	PULLED B (MM)										
30.0	SAMPLE W	.208	.213	.208	.208	.211	.209				
	.207	.209	.031	.031	.031	.031	.031				
	.207		.031	.031	.031	.031	.031				

AVERAGE DIAMETER .209 MM

STANDARD DEVIATION .002 MM

Configuration LBB+SB POLMER A . TEMP 180 C INSERT 0.3 MM

WIRE 0.03 MM DIAMETER EN58A STEEL WIRE

MEASURED DIAMETE (MM)

SAMPLE NO. RPM .208 DRAWING SPEED (m MEASUREMMEASUREM .205 .206 .205 .206 (mm)

SAMPLE NO.	RPM	DRAWING SPEED	MEASUREMMEASUREM (mm)					AVERAGE DIAMETER OF COATED WIRE (mm)	STANDARD DEVIATION	DIA. OF STRIPPED WIRE (mm)	COATING THICKNESS (mm*E-3)
033001B	65	.02	.032	.035	.031	.035	.035	.034	.002	.030	2 ± 2
033002B	102	.03	.031	.030	.031	.032	.031	.031	.001	.031	0.0 ± 1
033003B	218	.07	.036	.031	.042	.041	.041	.038	.004	.031	4 ± 4
033004B	282	.09	.031	.031	DISCONTINOUS COAT						
033005B	173	.06	.032	.032	.032	.032	.032	.032	.000	.031	1 ± 0
033006B	102	.03	.400	.390	.046	.044	.044	.043	.003		6 ± 3

Configuration SBB+GB POLMER A TEMP 180 C INSERT 0.25 MM

WIRE TINNED COPPER WIRE DIA. 0.15 NOMINAL

SAMPLE NO.	RPM	DRAWING SPEED (m/s)	MEASUREMMEASUREMENTES OF WIRE DIAMETER (mm)					AVERAGE DIAMETER OF COATED WIRE (mm)	STANDARD DEVIATION	COATING THICKNESS (mm*E-3)
172501A	117	.04	.204	.191	.200	.208	.203	.201	.006	19 ± 7
172502A	284	.09	.203	.193	.196	.196	.200	.198	.003	17 ± 4
172503A	443	.14	.203	.193	.196			.197	.004	17 ± 5
172504A	586	.19	.202	.198	.196	.194	.199	.198	.003	17 ± 4
172505A	731	.24	.209	.207	.207	.200	.205	.206	.003	21 ± 4
172506A	880	.29	.213	.211	.211	.208	.207	.210	.002	23 ± 3
172507A	1090	.35	.196	.206	.197	.204	.204	.201	.004	19 ± 5
172508A	1167	.38	.211	.211	.203	.210	.207	.208	.003	22 ± 4
172509A	1300	.42	.210	.207	.204	.202	.200	.204	.004	20 ± 5
172510A	1476	.48	.204	.207	.198	.195	.203	.201	.004	19 ± 5
172511A	1620	.53	.200	.197	.204	.198	.206	.201	.003	19 ± 4
172512A	1752	.57	.208	.202	.199	.204	.201	.203	.003	20 ± 4
172513A	1918	.62	.204	.207	.208	.202	.200	.204	.003	20 ± 4
172514A	2061	.67	.188	.190	.202	.198	.199	.195	.005	16 ± 6
172515A	2205	.72	.207	.196	.195	.199	.195	.198	.005	17 ± 6
172516A	2337	.76	.193	.193	.195	.186	.200	.193	.004	15 ± 5
172517A	2481	.81	.188	.192	.195			.192	.003	14 ± 4
172518A	2590	.84	.206	.203	.206	.201	.198	.203	.003	20 ±4
172519A	2645	.86	.199	.196	.202	.183	.206	.197	.008	17 ± 9

Configuration 5BB+6B POLMER A TEMP 180 C INSERT 0.25 MM

WIRE TINNED COPPER WIRE DIA. 0.21 NOMINAL

SAMPLE NO.	RPM	DRAWING SPEED (m/s)	MEASUREMENTES OF WIRE DIAMETER (mm)					AVERAGE DIAMETER OF COATED WIRE (mm)	STANDARD DEVIATION	COATING THICKNESS (mm*E-3)
212501A	64	.02	.220	.224	.231	.225	.225	.225	.004	8 ± 6
212502A	104	.03	.221	.223	.231	.225	.223	.225	.003	8 ± 5
212503A	101	.03	.222	.220	.225	.224	.214	.221	.004	6 ± 6
212504A	140	.05	.220	.221	.219	.222	.218	.220	.001	6 ± 3
212505A	239	.08	.219	.227	.221	.221	.228	.223	.004	7 ± 6
212506A	276	.09	.220	.221	.223	.220	.220	.221	.001	6 ± 3
212507A	345	.11	.224	.228	.221	.213	.221	.221	.005	6 ± 7
212508A	388	.13	.226	.226	.228	.221	.221	.224	.003	8 ± 5
212509A	411	.13	.219	.228	.226	.220	.221	.223	.004	7 ± 6
212510A	487	.16	.223	.229	.225	.221	.228	.225	.003	8 ± 5
212511A	575	.19	.227	.230	.224	.230	.226	.227	.002	9 ± 4
212512A	620	.20	.219	.221	.231	.225	.223	.224	.004	8 ± 6
212513A	665	.22	.223	.230	.228	.224	.228	.227	.003	9 ± 5
212514A	731	.24	.221	.223	.231	.229	.230	.226	.004	9 ± 6
212515A	811	.26	.228	.222	.221	.230	.222	.225	.004	8 ± 6
212516A	880	.29	.226	.229	.227	.223	.225	.226	.002	9 ± 4
212517A	923	.30	.223	.227	.224	.226	.228	.226	.002	9 ± 4
212518A	979	.32	.231	.227	.225	.227	.225	.227	.002	9 ± 4
212519A	1057	.34	.221	.229	.226	.225	.239	.228	.006	10 ± 8
212520A	1123	.36	.231	.223	.220	.227	.220	.224	.004	8 ± 6
212521A	1178	.38	.230	.226	.231	.225	.225	.227	.003	9 ± 5
212522A	1288	.42	.230	.225	.225	.224	.222	.225	.003	8 ± 5
212523A	1377	.45	.221	.224	.224	.223	.225	.223	.001	7 ± 3
212524A	1432	.47	.220	.223	.226	.224	.225	.224	.002	8 ± 4
212525A	1498	.49	.225	.230	.231	.228	.229	.229	.002	10 ± 4
212526A	1576	.51	.220	.223	.233	.223	.233	.225	.005	8 ± 7
212527A	1664	.54	.224	.222	.225	.223	.225	.224	.001	8 ± 3
212528A	1797	.58	.224	.226	.224	.221	.228	.223	.003	7 ± 5
212529A	1984	.64	.227	.220	.227	.220	.222	.223	.003	7 ± 5
212530A	2150	.70	.225	.224	.225	.226	.227	.225	.001	8 ± 3
212531A	2293	.74	.224	.228	.225	.223	.225	.225	.002	8 ± 4
212532A	2382	.77	.231	.224	.223	.222	.221	.224	.004	8 ± 6
212533A	2492	.81	.230	.225	.225	.224	.222	.225	.003	8 ± 5
212534A	2601	.85	.222	.222	.226	.231	.235	.227	.005	9 ± 7
212535A	2645	.86		.236	.224	.222	.217	.225	.007	8 ± 9

Configuration LBB+GB POLMER A TEMP 180 C INSERT 0.25 MM
WIRE TINNED COPPER WIRE DIA. 0.15 NOMINAL

SAMPLE NO.	DRAWING SPEED (M/S)	MEASUREMENTES OF WIRE DIAMETER (MM)					AVERAGE DIAMETER OF COATED WIRE	STANDARD DEVIATION	COATING THICKNESS (MM*E-3)
1	.080	.210	.213	.210	.211	.211	.211	.001	20 ± 2
7	.080	.212	.210	.213	.214	.216	.213	.002	21 ± 4
8	.102	.210	.217	.212	.209	.209	.211	.003	20 ± 4
2	.139	.217	.205	.209	.196	.207	.206	.007	18 ± 8
9	.139	.211	.212	.211	.205	.208	.209	.003	19 ± 4
10	.151	.209	.205	.204	.202	.210	.206	.003	18 ± 4
3	.193	.208	.204	.200	.202	.203	.205	.005	17 ± 6
4	.262	.185	.162	.181	.164	.163	.171	.010	0 ± 11
5	.296	.163	.164	.166	.159		.163	.003	3 ± 4
6	.341	.163	.164	.171	.164		.166	.003	2 ± 4

MEASUREMENTS OF THICKNESS OF UNCOATED TINNED COPPER WIRE

.171	.169	.170	.170	.169	.170	.17	.17
.169	.170	.170	.171				

AVERAGE THICKNESS .170
STANDARD DEVIATION .001

Configuration LBB+GB POLMER A TEMP 200 C INSERT 0.25 MM
WIRE TINNED COPPER WIRE DIA. 0.15 NOMINAL

SAMPLE NO.	DRAWING SPEED (M/S)	MEASUREMENTES OF WIRE DIAMETER (MM)					AVERAGE DIAMETER OF COATED WIRE	STANDARD DEVIATION	COATING THICKNESS (MM*E-3)
1	.076	.212	.211	.210	.209	.213	.211	.001	20 ± 2
7	.080	.191	.181	.194	.194	.196	.191	.005	10 ± 6
2	.113	.212	.210	.211	.212	.213	.212	.001	21 ± 2
8	.121	.182	.195	.192	.191	.180	.188	.006	9 ± 7
3	.137	.210	.208	.207	.207	.208	.208	.001	19 ± 2
9	.167	.200	.190	.203	.204	.192	.198	.006	14 ± 7
10	.176	.200	.206	.195	.215	.198	.203	.007	16 ± 8
4	.185	.207	.212	.210	.211	.212	.210	.002	20 ± 3
11	.203	.194	.188	.194	.204	.204	.194	.006	13 ± 7
5	.230	.206	.208	.210	.204	.205	.207	.002	18 ± 3
12	.256	.189	.197	.195	.204	.196	.196	.005	13 ± 6
6	.275	.195	.203	.201	.201	.197	.199	.003	14 ± 4

Configuration LBB+GB POLMER A TEMP 180 C INSERT 0.6 MM
WIRE TINNED COPPER WIRE DIA. 0.15 NOMINAL

SAMPLE NO.	RPM	DRAWING SPEED (m/s)	MEASUREMMEASUREMENTES OF WIRE DIAMETER (mm)					AVERAGE DIAMETER OF COATED WIRE (mm)	STANDARD DEVIATION	DIA. OF STRIPPED WIRE (mm)	COATING THICKNESS (mm*E-3)
176001A	102	.08	.393	.447	.342	.386	.440	.401	.038		119 ±39

ALL SAMPLES ABOVE THIS SPEED HD A DISCONTINOUS COAT

Configuration LBB+GB POLMER A TEMP 180 C INSERT 0.3 MM
WIRE TINNED COPPER WIRE DIA. 0.15 NOMINAL

SAMPLE NO.	RPM	DRAWING SPEED (m/s)	MEASUREMENTES OF WIRE DIAMETER (mm)					AVERAGE DIAMETER OF COATED WIRE (mm)	STANDARD DEVIATION	DIA. OF STRIPPED WIRE (mm)	COATING THICKNESS (mm*E-3)
173001A	104	.08	.216	.219	.211	.203	.212	.212	.005	.140	24 ± 6
173002A	273	.22	.231	.240	.226	.215	.220	.226	.009	.126	31 ± 10
173003A	443	.36	.208	.245	.240	.235	.238	.233	.013	.146	35 ± 14
173004A	586	.48	.225	.222	.242	.221	.227	.227	.008	.162	32 ± 9
173005A	743	.60	.223	.235	.219	.211	.210	.220	.009	.142	28 ± 10
173006A	880	.71		.218	.207	.200	.187	.203	.011	.133	20 ± 12
173007A	1013	.82	.214	.205	.206	.217	.224	.213	.007	.153	25 ± 8
173008A	1178	.96	.171	.168	.187	.206	.178	.182	.001	.158	9 ± 2
173010A	1277	1.04	.163	.158	.161	.161	.163	.161	.002		-3 ± 3
173009A	1443	1.17	.162	.174	.177	.185	.189	.177	.009		7 ± 10
173011A	1586	1.29	.157	.161	.160	.161	.157	.159	.002		3 ± 3
173012A	1796	1.46		.161	.158	.161	.160	.160	.001		-2 ± 2
173013A	1929	1.57	.161	.161	.162	.163	.160	.161	.001		-3 ± 2
173014A	2050	1.67	.153	.157	.160	.157	.161	.158	.003		3 ± 4

Configuration LBB+GB POLMER A TEMP 180 C INSERT 0.3 MM
WIRE TINNED COPPER WIRE DIA. 0.21 NOMINAL

SAMPLE NO.	RPM	DRAWING SPEED (m/s)	MEASUREMENTES OF WIRE DIAMETER (mm)					AVERAGE DIAMETER OF COATED WIRE (mm)	STANDARD DEVIATION	DIA. OF STRIPPED WIRE (mm)	COATING THICKNESS (mm*E-3)
216001A	102	.08	.228	.244	.217	.244	.229	.232	.010	.168	12 ± 12
216002A	296	.24	.251	.238	.251	.242	.241	.245	.005	.197	18 ± 7
216003A	443	.36	.245	.249	.253	.246	.249	.248	.003	.180	20 ± 5
216004A	587	.48									
216005A	743	.60	.247	.238	.238	.239	.245	.241	.004	.185	16 ± 6
216006A	869	.71	.213	.212	.237	.220	.206	.218	.011	.205	5 ± 13
216008A	902	.73	.233	.220	.253	.230	.236	.234	.011	.165	13 ± 13
216007A	1034	.84	.256	.241	.254	.241	.236	.246	.008	.203	19 ± 10
216009A	1234	1.00	.210	.210	.206	.211	.211	.210	.002	.169	1 ± 4
216010A	1300	1.06	.213	.207	.207	.210	.200	.207	.004	.176	-2 ± 6

Configuration LBB+GB POLMER A TEMP 180 C INSERT 0.3 MM
WIRE HIGH TENSILE STEEL DIA. 0.2 MM.

SAMPLE NO.	RPM	DRAWING SPEED (m/s)	MEASUREMENTES OF WIRE DIAMETER (mm)					AVERAGE DIAMETER OF COATED WIRE (mm)	STANDARD DEVIATION	DIA. OF STRIPPED WIRE (mm)	COATING THICKNESS (mm*E-3)
203001A	102	.08	.225	.225	.224	.233	.218	.225	.005	.203	10 ± 6
203007A	102	.08	.237	.238	.235	.235	.236	.236	.001	.205	15 ± 2
203008A	140	.11	.238	.242	.239	.238	.252	.242	.005	.205	18 ± 6
203006A	185	.15	.235	.242	.250	.234	.244	.241	.006	.205	18 ± 7
203005A	251	.20	.234	.240	.234	.219	.213	.228	.010	.207	11 ± 11
203002A	262	.21	.239	.221	.223	.224	.249	.231	.011	.205	13 ± 12
203004A	410	.33	DISCONTINOUS COAT								
203003A	441	.36	DISCONTINOUS COAT								

Configuration LBB+GB POLMER B TEMP 145 C INSERT 0.6 MM
WIRE TINNED COPPER WIRE DIA. 0.15 NOMINAL

SAMPLE NO.	RPM	DRAWING SPEED (m/s)	MEASUREMENTES OF WIRE DIAMETER (mm)					AVERAGE DIAMETER OF COATED WIRE (mm)	STANDARD DEVIATION	DIA. OF STRIPPED WIRE (mm)	COATING THICKNESS (mm*E-3)
176009B	103	.08	.386	.461	.469	.276	.513	.421	.083	.163	129 ± 84
176001B	104	.08	.416	.408	.416	.414	.389	.409	.010	.155	123 ± 11
176002B	272	.22	.418	.354	.412	.368	.350	.380	.029	.159	108 ± 30
176008B	345	.28	.438	.440	.468	.442	.498	.457	.023	.156	147 ± 24
176003B	466	.38	.164	.382	.166	.316	.217	.249	.086	.157	43 ± 87
176007B	494	.40	.459	.445	.469	.488	.449	.462	.015	.158	149 ± 16
176004B	598	.49	.516	.478	.160	.415	.439	.401	.126	.156	119 ± 127
176006B	620	.50	.163	.471	.260	.167	.448	.302	.134	.158	69 ± 135
176005B	755	.61	.437	.374	.209	.190	.403	.323	.103	.155	8 ± 104

Configuration LBB+GB POLMER B TEMP 145 C INSERT 0.6 MM
WIRE TINNED COPPER WIRE DIA. 0.21 NOMINAL

SAMPLE NO.	RPM	DRAWING SPEED (m/s)	MEASUREMENTES OF WIRE DIAMETER (mm)					AVERAGE DIAMETER OF COATED WIRE (mm)	STANDARD DEVIATION	DIA. OF STRIPPED WIRE (mm)	COATING THICKNESS (mm*E-3)
216001B	102	.08	.455	.493	.444	.410	.481	.457	.029	.204	124 ± 31
216006B	103	.08	.537	.554	.500	.498	.496	.517	.024	.200	154 ± 26
206007B	238	.19	.563	.551	.541	.544	.565	.552	.010	.201	172 ± 12
216002B	323	.26	.555	.567	.519	.557	.562	.552	.017	.203	172 ± 19
206008B	432	.35	.563	.543	.562	.574	.541	.557	.013	.200	174 ± 15
216003B	451	.37	.516	.496	.492	.514	.519	.507	.011	.209	149 ± 13
216004B	588	.48	.546	.515	.486	.527	.481	.511	.025	.200	151 ± 27
216009B	588	.48	.488	.525	.483	.461	.476	.487	.021	.207	139 ± 23
216005B	733	.60	.209	.459	.493	.212	.534	.381	.142	.210	86 ± 144
206010B	880	.71	.528	.485	.212	.312	.207	.349	.135	.197	70 ± 137

Configuration LBB+GB POLMER B TEMP 145 C INSERT 0.6 MM
WIRE HIGH TENSILE STEEL DIA. 0.2 MM.

SAMPLE NO.	RPM	DRAWING SPEED (m/s)	MEASUREMENTES OF WIRE DIAMETER (mm)					AVERAGE DIAMETER OF COATED WIRE (mm)	STANDARD DEVIATION	DIA. OF STRIPPED WIRE (mm)	COATING THICKNESS (mm*E-3)
206001B	118	.10	.545	.571	.478	.570	.472	.527	.044		161 ± 45
206002B	284	.23	.557	.567	.569	.523	.557	.555	.017	.205	175 ± 18
206004B	342	.28	.580	.523	.463	.560		.532	.045	.209	163 ± 46
206003B	455	.37	DISCONTINOUS COAT								

Configuration LBB+GB POLMER A TEMP 180 C INSERT 0.6 MM
WIRE TINNED COPPER WIRE DIA. 0.21 NOMINAL

SAMPLE NO.	RPM	DRAWING SPEED (m/s)	MEASUREMMEASUREMENTES OF WIRE DIAMETER (mm)					AVERAGE DIAMETER OF COATED WIRE (mm)	STANDARD DEVIATION	DIA. OF STRIPPED WIRE (mm)	COATING THICKNESS (mm*E-3)
213001A	103	.08	.487	.457	.446	.430	.405	.445	.027	.195	118 ± 29
213002A	262	.21	.544	.571	.542	.543	.585	.558	.018	.199	175 ± 19
213003A	455	.37	.566	.572	.559	.560	.544	.564	.005	.181	178 ± 7
213004A	587	.48	.534	.491	.375	.265	.468	.427	.096	.185	109 ± 98
113005A	745	.61	COATING NEARLY CONTINOUS								
213006A	891	.72	SPORADIC COATING								
213007A	1035	.84	SPORADIC COATING								
213008A	1156	.94	SPORADIC LUMPS OF POLYMER								
213009A	1289	1.05	SPORADIC LUMPS OF POLYMER								
213010A	1465	1.19	.210	.201	.207	.208	.215	NO COATING			

Configuration LBB+GB POLMER B TEMP 145 C INSERT 0.3 MM
WIRE TINNED COPPER WIRE DIA. 0.15 NOMINAL

SAMPLE NO.	RPM	DRAWING SPEED (m/s)	MEASUREMENTES OF WIRE DIAMETER (mm)					AVERAGE DIAMETER OF COATED WIRE (mm)	STANDARD DEVIATION	DIA. OF STRIPPED WIRE (mm)	COATING THICKNESS (mm*E-3)
173001B	102	.08	.186	.188	.187	.189	.188	.188	.001	.150	12 ± 2
173002B	262	.21	.191	.191	.174	.179	.183	.184	.007	.157	10 ± 8
173003B	442	.36	.185	.186	.188	.200	.187	.189	.005	.155	13 ± 6
173004B	515	.42	.204	.181	.183	.199	.200	.193	.009	.157	15 ± 10
173005B	742	.60	.191	.190	.200	.208	.208	.199	.008	.155	18 ± 9
173006B	891	.72	.237	.230	.199	.207	.226	.220	.014	.155	28 ± 15
173007B	1035	.84	.206	.206	.208	.203	.204	.206	.002	.154	21 ± 3
173008B	1189	.97	.212	.207	.199	.198	.193	.202	.068	.156	19 ± 7
173009B	1300	1.06	.196	.203	.199	.201	.205	.201	.031	.154	19 ± 4
173010B	1455	1.18	.202	.206	.206	.197	.224	.207	.009	.153	22 ± 10
173011B	1620	1.32	.187	.227	.202	.205	.204	.205	.012	.156	21 ± 13
173012B	1764	1.43	.177	.193	.175	.200	.202	.189	.011	.155	13 ± 12
173013B	1918	1.56	DISCONTINOUS COATING								
173014B	1918	1.56	.198	.220	.204	.212	.202	.207	.008	.161	22 ± 9
173015B	2073	1.68	DISCONTINOUS COATING								

Configuration LBB+GB POLMER B TEMP 145 C INSERT 0.3 MM
WIRE TINNED COPPER WIRE DIA. 0.21 NOMINAL

SAMPLE NO.	RPM	DRAWING SPEED (m/s)	MEASUREMENTES OF WIRE DIAMETER (mm)					AVERAGE DIAMETER OF COATED WIRE (mm)	STANDARD DEVIATION	DIA. OF STRIPPED WIRE (mm)	COATING THICKNESS (mm*E-3)
213001B	66	.05	.242	.236	.237	.244	.241	.240	.003	.201	16 ± 5
213002B	173	.14	.241	.240	.241	.240	.240	.240	.000	.197	16 ± 2
213003B	285	.23	.248	.240	.248	.232	.249	.243	.007	.201	17 ± 9
213004B	442	.36	.248	.241	.258	.254	.249	.250	.006	.202	21 ± 8
213005B	584	.47	.247	.240	.243	.242	.243	.243	.002	.192	17 ± 4
213006B	731	.59	.235	.239	.248	.239	.244	.241	.005	.203	16 ± 7
213007B	902	.73	.260	.246	.241	.243	.254	.249	.007	.202	20 ± 9
213008B	1013	.82	.239	.248	.241	.240	.238	.241	.004	.210	16 ± 6
213009B	1178	.96	.250	.239	.234	.235	.245	.241	.006	.199	16 ± 8
213010B	1298	1.05	.236	.244	.251	.235	.242	.242	.006	.200	17 ± 8
213013B	1454	1.18	.238	.241	.242	.238	.250	.242	.004	.192	17 ± 6
213012B	1641	1.33	.235	.238	.232	.238	.240	.237	.003	.197	14 ± 5
213011B	1762	1.43	.241	.234	.230	.242	.241	.238	.005	.196	15 ± 7

Configuration LBB+GB POLMER B TEMP 145 C INSERT 0.3 MM
WIRE HIGH TENSILE STEEL DIA. 0.2 MM.

SAMPLE NO.	RPM	DRAWING SPEED (m/s)	MEASUREMENTES OF WIRE DIAMETER (mm)					AVERAGE DIAMETER OF COATED WIRE (mm)	STANDARD DEVIATION	DIA. OF STRIPPED WIRE (mm)	COATING THICKNESS (mm*E-3)
203001B	103	.08	.230	.235	.230	.231	.226	.230	.003	.207	12 ± 4
203008B	103	.08	.243	.251	.234	.245	.242	.243	.005	.204	19 ± 6
203002B	272	.22	.241	.230	.236	.223	.231	.232	.006	.208	13 ± 7
203007B	375	.30	.230	.253	.240	.241	.239	.241	.007	.203	18 ± 8
203003B	443	.36	.232	.243	.235	.236	.251	.239	.007	.205	17 ± 8
203004B	609	.49	.237	.243	.246	.234	.233	.239	.005	.207	17 ± 6
203005B	744	.60	.238	.243	.241	.233	.235	.238	.004	.207	16 ± 5
203006B	924	.75	DISCONTINOUS COATING							.206	

APPENDIX F

This appendix contains extracts frm the West 3300 Temperature Controller Manual (15) and the Variac for the Motor (16) along with a block layout of the bench's electrical circuits.

Temperature Controller

West 3300 :-

Input Voltage	220/240 V Nomnal 50/60 Hz
Input Thermocuple	'J' 0 - 450 °C
Heat Output	Relay

SECTION 4 SETTING UP PROCEDURES

4.1 CONTROLS AND DISPLAYS

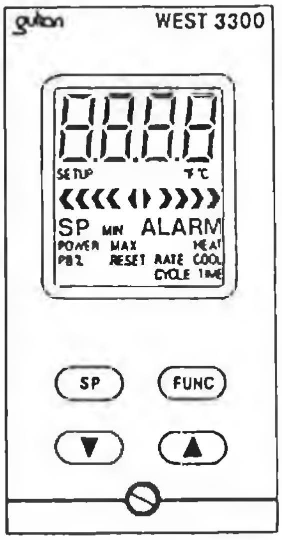


FIGURE 4-1 INSTRUMENT FRONT PANEL

4.1.1 Displays

Numeric Display	This indicates numerical information relating to the function selected. Where the value is a temperature °C or °F will also be displayed.
Bargraph Display ❮❮❮❮ ❮❯ ❯❯❯❯ BLUE / \ RED GREEN	Both green chevrons displayed indicates that PV is within 1% of SP Each blue or red chevron indicates a deviation of 1% high (red) or 1% low (blue).
Legends	HEAT, COOL and ALARM are used as output indicators in User Mode (see Section 4.5) and as parameter labels in Setup Mode. SETUP shows that the controller is in Setup Mode. SP, POWER, PB%, RESET, RATE, CYCLE, TIME, MAX, MIN are used singly and in combination as parameter labels.

4.6 FRONT PANEL LEGENDS (SETUP MODE)

When the controller is in Setup Mode, HEAT, COOL and ALARM are used to indicate parameter selection, and do not indicate that an output is active.

Table 4.1 shows the parameters and their legends in the order in which they are selected by the FUNC button in Setup Mode. Where a parameter is for an optional feature which is not fitted, or where the parameter is invalidated by another parameter setting (e.g. PB% set to 0), the parameter is skipped in the sequence.

Parameter	Legend	Range	Default Value
Process Variable	None	Span of Instrument	Read Only
Set-point	SP	Between SP MIN and SP MAX	Range min
Output Power	POWER	‡-100% to +100%	Read Only
Proportional Band	PB%	0 to 100% of span	10%
*Integral Time Constant	RESET	10 sec to 30 min	5 min 00 s
*Derivative Time Constant	RATE	00 sec to 10 min	30 sec
*Relative Cool Gain	COOL PB%	0.02 to 1.00 and ON/OFF (>1.00)	1.00
*Overlap	HEAT COOL PB%	-20% to +20% of PB	0
†On/Off Differential	PB% RESET HEAT : COOL	0.1 to 10.0% of span	0.5%
SP High Limit	SP MAX	SP to range max	Range max
SP Low Limit	SP MIN	Range min to SP	Range min
*Heat Power Limit	POWER MAX	0 to 100% of full pwr	100%%
*Heat Cycle Time	HEAT CYCLE TIME	1/2, 1, 2, 4, 8, 16, 32, 64 sec	32 sec
*Cool Cycle Time	COOL CYCLE TIME	1/2, 1, 2, 4, 8, 16, 32, 64 sec	32 sec
¶Cool Value	COOL	± Span from SP	0
§Process Alm Val	ALARM	Range min to range max	Range max
§Band Alarm Val	ALARM	0 to Span from SP	5 Units
§Dev Alarm Val	ALARM	± Span from SP	5 Units

TABLE 4-1 PARAMETER LEGENDS, RANGES AND DEFAULT VALUES

NOTES 'Span' = Span of instrument i.e. range max - range min

* The functions are not operative or accessible if PB% is set to 0

‡ 0 to 100% on instruments with HEAT output only or with COOL output set to On/Off.

§ These functions are optional. See Section 4.10. for details of Alarm operation.

† If PB% = 0 the display shows PB% RESET HEAT. If Cool Output is fitted and Relative Cool Gain set to OFF, display shows PB% RESET COOL. If PB% = 0 and Cool Output is fitted the display shows PB% RESET HEAT COOL.

¶ Accessible ony of COOL output is fitted and set to On/Off.

When the controller is delivered from the factory parameters are set to the default values shown in the table. Once set the working values are held in a memory with battery back-up. If the configuration of the controller is changed, the controller reverts to operating with the default values. This action is signalled to the operator by the numeric display showing decimal points after every digit. When any parameter, apart from set-point, is set again, the display reverts to normal.

4.7 CONTROL PARAMETERS

4.7.1 Proportional Band

Can be set between 0 and 100% of span of instrument. If set to 0 the controller operates in On/Off mode.

4.7.2 Integral Time Constant (RESET) - Skipped if PB% = 0

Can be set to between 10 sec and 30 min. If raised above 30 min it becomes inoperative, and the numeric display is blank

4.7.3 Derivative Time Constant (RATE) - Skipped if PB% = 0

Can be set to between 0 sec and 10 min.

4.7.4 Relative Cool Gain (COOL PB%) - Skipped if PB% = 0 or no COOL output fitted.

This defines the Cool gain relative to Heat, within the Proportional Band, and the maximum Cool outside the Proportional Band. It can be set between 0.02 and 1.00. If it is raised above 1.00 the display shows blank and the Cool output operates in On/Off mode.

4.7.5 Overlap/Deadband (HEAT COOL PB%) - Skipped if PB% = 0, or COOL not fitted or set to On/Off.

This defines the area within the proportional band where Heat and Cool are both active (0 to +20%) or the area where neither is active (0 to -20%)

4.7.6 On/Off Differential (PB% RESET) - Skipped unless PB% = 0 or COOL set to On/Off

This applies to Heat and Cool Outputs if the Proportional Band is set to zero, and to Cool Output if Relative Cooling Gain is set to On/Off. It provides a dead band to prevent too frequent load switching, and can be set to between 0.1 and 10% of span of instrument.

4.7.7 Set-point Minimum and Set-point Maximum (SP MIN, SP MAX)

These should be set so that in User Mode the operator cannot adjust the Setpoint to a value which might damage the process.

4.7.8 Heat Output Power Limit (POWER MAX) - Skipped if PB% = 0

This is used to limit the power level of Heat output and may be used to protect the process. If no process protection is required, it may be set at 100%.

4.7.9 Heat Output Cycle Time (HEAT CYCLE TIME) - Skipped if PB% = 0

The selection of cycle times depends on the type of process to be controlled. For relay outputs, the cycle time should be as large as possible (consistent with satisfactory control) in order to maximise relay life. If the instrument has the SSR output option, the cycle time can be selected from the lower values in the range. The values available are 1/2, 1, 2, 4, 8, 16, 32 and 64 seconds.

4.7.10 Cool Output Cycle Time (COOL CYCLE TIME) - Skipped if PB% = 0 or COOL not fitted or set to On/Off.

This can be selected in the same way as Heat Cycle Time.

4.7.11 Cool Output Deviation Value (COOL) [Action opposite to HEAT]

This parameter is not accessed unless Cool Output is set for On/Off operation. With Cool Output direct acting, it will switch on at SP + COOL + 1/2 PB% RESET (On/Off Differential) and switch off at SP + COOL - 1/2 PB% RESET. Note that COOL can be set to a negative value, and in this case the above formulae are still applicable but Cool Output switches on below the set-point.

4.8 TUNING THE CONTROLLER (HEAT OUTPUT ONLY)

BEFORE STARTING TO TUNE THE INSTRUMENT TO THE LOAD, CHECK THAT POWER MAX IS SET TO THE REQUIRED LEVEL. (See 4.7.6) AND HEAT CYCLE TIME SET TO A SUITABLE VALUE (See 4.7.9)

The following is a simple technique for determining values for proportional band (PB%), derivative (RATE) and integral (RESET).

NOTE: The techniques are suitable only for processes that are not harmed by large fluctuations in the process variable. They provide an acceptable basis from which to start fine tuning for a wide range of processes. For additional information on tuning, including alternative tuning techniques, refer to the book 'Principles of Temperature Control', available from WEST.

Option 1

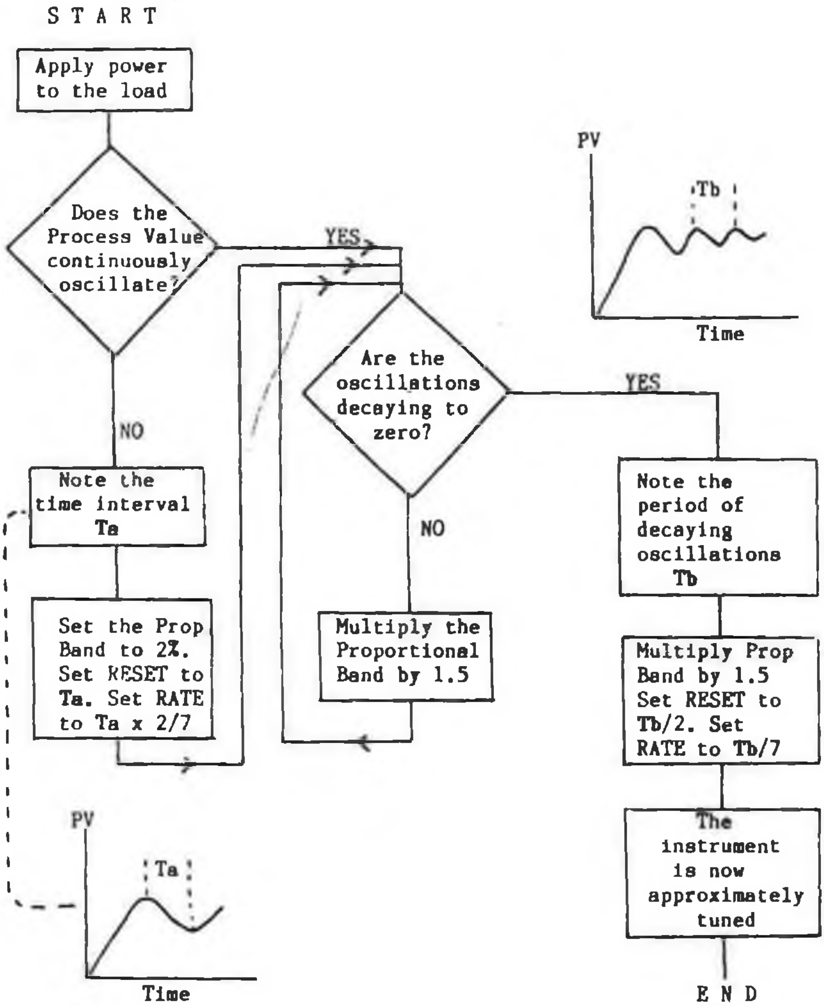
1) Set the setpoint to the normal operating process value (lower if overshoot beyond this value is likely to cause damage).

2) Set the proportional band (PB%) to 1%: integral (RESET) to OFF (to turn the integral off, raise RESET until the numeric display is blank) and set the derivative (RATE) to zero.

3) Follow the instructions in Fig. 4-2. At each stage,allow sufficient time before moving on to the next stage.

   A self-tuning version of the controller, the 3400, is available, and this automatically optimises the control parameters to suit the application. It compensates for any changes to the operating conditions.

SETTING UP PROCEDURES



AFTER SETTING UP THE PARAMETERS, SET THE CONTROLLER TO USER MODE (SEE 4.2) TO PREVENT UNAUTHORISED ADJUSTMENT OF THE VALUES

Option 2

1) Set the setpoint to the normal operating process value (or lower if overshoot beyond this value is likely to cause damage).

2) Set the proportional band (PB%) to 0% and On/Off Differential to 0.1%; (this sets the instrument to ON/OFF control, and RESET and RATE will be skipped on the front panel).

3) Switch on the power supply to the heater.

Under these conditions the process will oscillate about setpoint, and the following parameters should be noted:

a) The peak to peak variation (P) of the first cycle (i.e. the difference between the highest value of the first overshoot and the lowest value of the first undershoot).

b) The cycle time (T) of this oscillation in minutes (see Fig. 4-3).

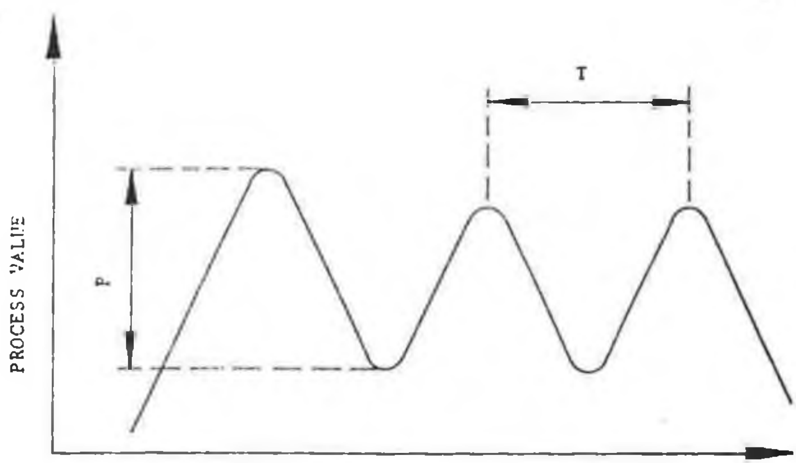


FIGURE 4-3 OPTION 2 SETTING UP PROCEDURE

SETTING UP PROCEDURES

4) The control setting should then be set as follows:

Proportional band (PBAND%) $= \frac{P}{\text{scale range}} \times 100$

Integral time (RESET) = T minutes
Derivative time (RATE) = T/6 minutes.

AFTER SETTING UP THE PARAMETERS, SET THE CONTROLLER TO USER MODE (SEE SECTION 4.2) TO PREVENT UNAUTHORISED ADJUSTMENT TO THE VALUES

Variac Controller

Anschlußplan ////////////////////////// Wiring diagramm ////////////////////// Schéma de branchement //////////

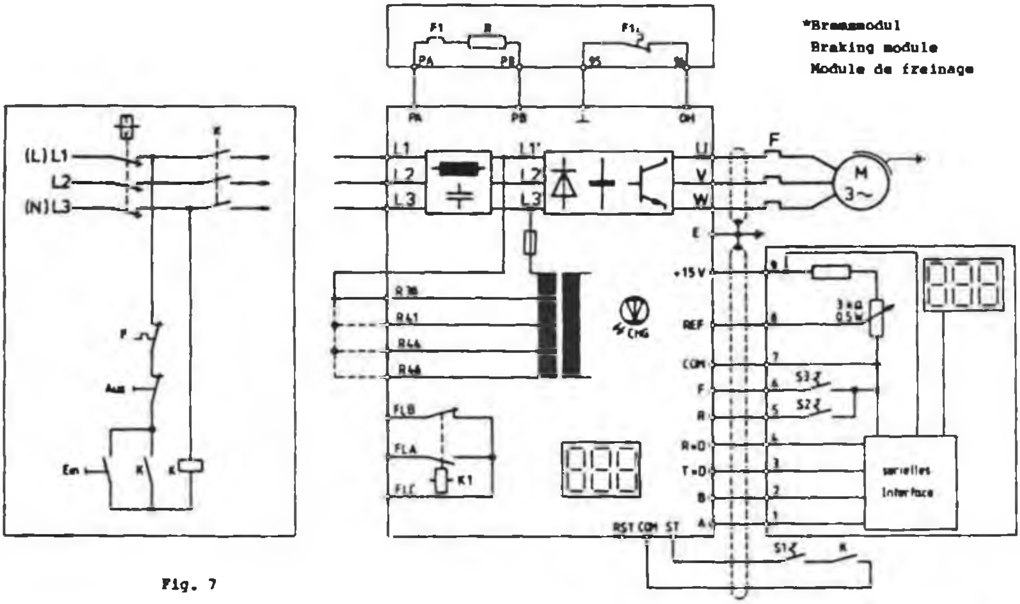


Fig. 7

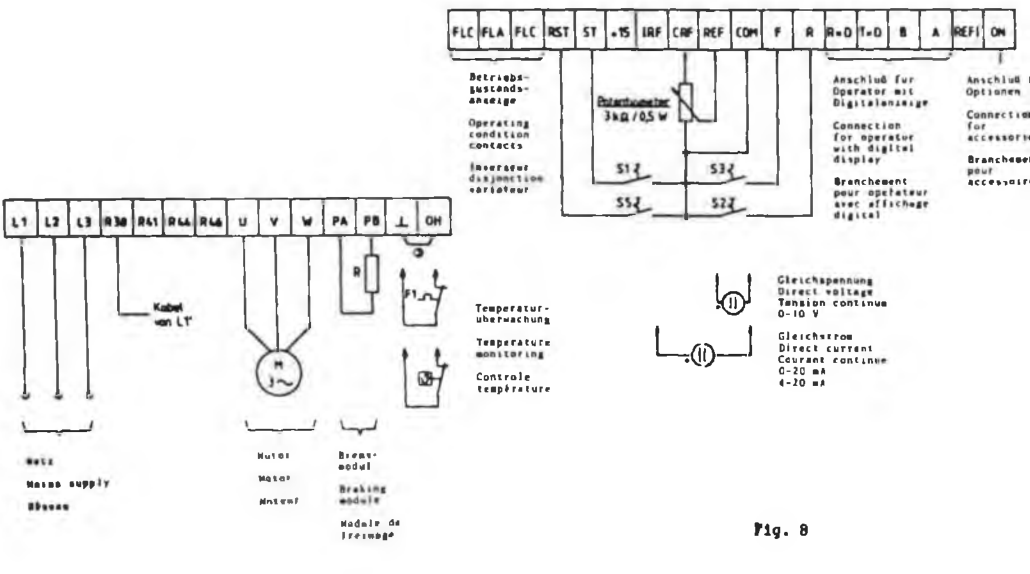


Fig. 8

F-7

Das Schütz "K" schaltet den KEB-COMBIVERT an das Versorgungsnetz.

Für den Schutz des Motors vor zu hoher Belastung können thermische Motorstromauslöser (F) oder Thermofühler installiert werden.

Thermofühler mit mechanischen Kontakten (Kontaktart: Öffner) können im Schwachstromkreis an die Klemmen ⊥ und OH angeschlossen werden.

Während des Betriebes und für kurze Zeit nach dem Ausschalten der Netzspannung sind im KEB-COMBIVERT noch Kondensatoren geladen. Solange die LED "Charge" auf der Treiberplatine leuchtet, befindet sich im Treiber- und Leistungsteil Hochspannung! Achtung Lebensgefahr!

Erdleiteranschluß unbedingt mit der kürzestmöglichen Leitung mit Haupterde verbinden.

S1 = Reglerfreigabe
S2 = Drehrichtung rückwärts
S3 = Drehrichtung vorwärts
(S3 hat Priorität vor S2)
S5 = Reset-Taster

Erläuterungen:

*Zubehör

2 Bei Anschluß einer Temperaturüberwachung ist diese Brücke zu entfernen.

The contactor "K" connects the KEB-COMBIVERT to the mains supply.

To protect the motor from overloading, the use of thermal motor current tripping devices (F) or temperature sensors is recommended.

Temperature sensors with mechanical contacts (normally closed contacts) can be connected to terminals ⊥ and OH in the low-voltage circuit.

The capacitors are charged during operation and remain charged for a short time after the mains voltage is switched off. Throughout the whole time that "Charge" LED remains lit, there is high voltage present in the driver and power stage! Danger of severe electric shock or fatality!

It is absolutely essential that the earth terminal is connected by the shortest possible wiring to the main earth.

S1 = Control release
S2 = Anticlockwise direction of rotation
S3 = Clockwise direction of rotation
(S3 has priority over S2)
S5 = Reset button

Explanations:

*Accessories

2 When temperature monitoring is used, this jumper must be removed.

Par le relais "K", la KEB-COMBIVERT est connecté au réseau.

Pour protéger le moteur contre les surcharges, l'utilisation de protections thermiques (F) ou de sondes thermo-statiques est recommandée.

Les sondes thermostatiques avec des contacts à ouverture peuvent être connectés aux bornes ⊥ et OH du circuit basse tension.

Une LED rouge s'allume dés la mise sous tension. Lors de la mise hors service de l'appareil, la LED reste allumée (temps court) durant la décharge progressive des condensateurs.
Attention aux risques d'electrocution: ne pas intervenir tant que la LED n'est pas éteinte.

Le raccordement du conducteur de terre doit être connecté par le câble le plus court possible à la terre principale.

S1 = Activation variateur
S2 = Sens de rotation antihoraire
S3 = Sens de rotation horaire
(S3 à priorité sur S2)
S5 = Remise à zéro

Definitions:

*Accessoires

2 Lorsqu'une thermo-sonde est utilisée, le shunt doit être entlevé.

Über die Kontakte FLA, FLB und FLC kann der Betriebszustand des KEB-COMBIVERT überwacht werden. Schaltet der KEB-COMBIVERT auf Störung (Überspannung, Unterspannung, Überstrom, Kurzschluß, Erdschluß, Übertemperatur, kurzzeitiger Phasenausfall), zieht das Relais K1 an (Kontaktbelastbarkeit 250 VAC/3,0 A).

Durch eine zusätzliche Temperaturüberwachung, z.B. im Schaltschrank, KEB-COMBIVERT, Motor oder Bremsmodul, kann durch einen geöffneten Kontakt an den Klemmen OH und $\perp$ ein Abschalten des KEB-COMBIVERT bewirkt werden.

Die Ursache der Störung wird mit der 3stelligen 7-Segment-Anzeige auf der Steuerplatine angezeigt (Kapitel 5).

Nach Beheben der Störung kann durch erneutes Starten des KEB-COMBIVERT entweder durch kurzzeitiges Verbinden der Klemmen RST mit COM oder durch Aus- und Wiedereinschalten der gesamten Spannungsversorgung vorgenommen werden. (Nicht bei OL!)

Treten mehrmals Störungsmeldungen auf, ist eine Überprüfung der Betriebsbedingungen oder der Antriebseinheit unbedingt erforderlich.

Bitte informieren Sie uns über die Art Ihres Antriebes, technische Daten, Netzversorgung und Umgebungsbedingungen.

The working condition of the KEB-COMBIVERT can be monitored by means of contacts FLA, FLB and FLC. If the KEB-COMBIVERT detects a fault (overvoltage, undervoltage, overcurrent, short circuit, earth fault, excess temperature, short-time phase loss) relay K1 is actuated (capacity of contacts: 250 VAC/3.0 A).

Disconnection of the KEB-COMBIVERT can be achieved by additional temperature monitoring, e.g. installed in the switch cabinet, KEB-COMBIVERT, motor or braking module, and an opened contact at terminals OH and $\perp$.

The cause of the fault is indicated on the control card by the 3-digit 7-segment display (section 5).

After the fault has been rectified, the KEB-COMBIVERT can be restarted by briefly connecting terminals RST and COM, or by switching the mains supply off and on again. (Not at OL!)

If the fault repeatedly occurs, the operating conditions or the drive unit must be checked immediately.

Please let us have details of your drive, technical data, mains supply and ambient conditions.

Un disjoncteur électronique protége le variateur des surtensions, soustensions, court-circuits, échauffement anormal et microcoupures. Le déclenchement de ce disjoncteur est signalé par le fonctionnement d'un relais inverseur (capacité des contacts: 250 VAC/3,0 A) bornes: FLA, FLB, FLC (FLA, FLC disjoncté; FLB, FLC - normal).

Un dispositif de contrôle de température, installé dans l'armoire de commande, sur le moteur, ou sur le module de freinage provoque,par l'ouverture d'un contact entre les bornes OH et $\perp$ la mise en securité du variateur.

La cause du déclenchement est visualisée sur la carte de commande par un indicateur digital 7 segments (chap. 5).

Lorsque la cause de mise en sécurité du KEB-COMBIVERT à été supprimée, la remise en fonctionnement de celui-ci est obtenue soit par un reset extérieur relier RST et COM , soit en coupant le secteur et en le réenclenchant. (Pas pour OL!)

En cas de mises en sécurité répétées, les conditions de fonctionnement ainsi que le circuit de commande doivent être vérifiés.

Si le probléme persiste, veuillez, s.v.p. nous informer des caractéristiques utilisées, de la tension d'alimentation, des conditions ambiantes, etc.

5. Beschreibung-Display /////////////

Wird der KEB-COMBIVERT eingeschaltet, müssen kurzzeitig alle Segmente des 3steiligen 7-Segment-Displays aufleuchten. Nach dieser Initialisierungsphase zeigt das Display je nach Stellung des Wahlschalters S1 die Betriebszustände bzw. Parameter an. Nach dem Einschalten des KEB-COMBIVERT werden die mit den Trimmern RH1 bis RH8 eingestellten Werte übernommen und können während des Betriebes nur dann direkt übernommen werden, wenn der entsprechende Trimmer mit Wahlschalter S1 angewählt ist.

5. Display details //////////////////

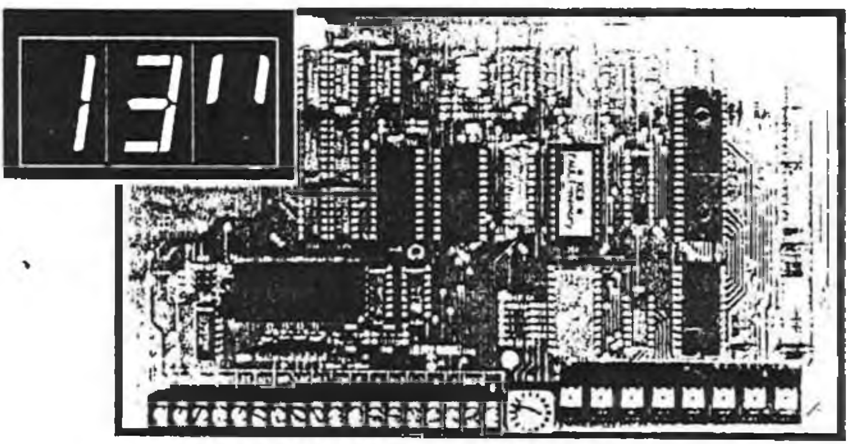
When the KEB-COMBIVERT is switched on, all the segments of the 3-digit 7-segment display must light up briefly. After this initialization phase the display will show the operating conditions or parameters depending on the position of selector switch S1. After the KEB-COMBIVERT has been switched on, the values set by trimmers RH1 to RH8 are accepted and can be directly accepted during operation only when the appropriate trimmer is selected by selector switch S1.

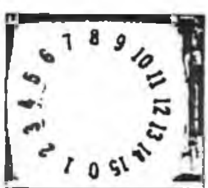
5. Indication affichage /////////

Lorsque le KEB-COMBIVERT est raccordé au réseau, tous les segments des indicateurs s'allument un court instant., Après cette phase d'utilisation l'indicateur affiche, en fonction de la position du commutateur S1, les conditions de fonctionnement ou les paramètres de réglage. Lorsque le KEB-COMBIVERT est enclenché, les différentes valeurs des paramètres, ajustées par les trimmers RH1 à RH8, sont acceptées. Ces valeurs peuvent également être modifiées, et acceptées, pendant le fonctionnement seulement si le trimmer correspond au paramètre à modifier à bien été sélectionné par le commutateur S1.

7-Segment Display
7-Segment Display
Indication a 7 Segments

Steuerplatine
Control board
Carte de commande





Wahlschalter

Trimmer / LED

Wahlschalter S1 //////////////////// Selector Switch S1 ///////////////// Commutateur S1 //////////////////

Wahlschalter S1 Selector Switch S1 Commutateur S1	Display Display Indication	Einheit Unit Unité	Bedeutung Sense Sens	Einstellbar Adjustable over Adjustable sur
Pos. 0/9/10	38	Hz	aktuelle Ausgangsfrequenz current output frequency fréquence de sortie actuelle	Sollwert set value valeur de consigne
Pos. 1	18	%	Drehmomentanhebung (Boost) Torque increase (boost) Augmentation de couple	RH 1 (Boost)
Pos. 2	50	Hz	Frequenz, bei der U_N erreicht wird Frequency, on which U_N is achieved Fréquence á laquelle on atteint U_N	RH 2 ($fU_{max.}$)
Pos. 3	20	Hz	Minimalfrequenz minimum frequency fréquence mini	RH 3 ($f_{min.}$)
Pos. 4	60	Hz	Maximalfrequenz maximum frequency fréquence maxi	RH 4 ($f_{max.}$)
Pos. 5	2''	s	Beschleunigungszeit (t_{ACC}) Acceleration time (t_{ACC}) temps d'accélération (t_{ACC})	RH 5 (ACC)
Pos. 6	2 1''	s	Verzögerungszeit (t_{DEC}) Deceleration time (t_{DEC}) temps décélération (t_{DEC})	RH 6 (DEC)
Pos. 7	10	%	Zeitabh. Boost (addiert zu Pos. 1) time-dep.boost (added to pos. 1) boost dépendant du temps (additionné á pos. 1)	RH 7 (- Boost)
Pos. 8	05''	s	Wirkzeit von Pos. 7 reaction time of pos. 7 temps de réaction de pos. 7	RH 8 (t-Boost)
Pos. 9/10	38	Hz	wie Pos. 0 as pos. 0 comme pos. 0	Sollwert set value valeur de consigne
Pos. 11	83	%	Spitzenauslastung während t_{ACC} peak load during t_{ACC} charge de pointe pendant t_{ACC}	
Pos. 12	61	%	Spitzenauslastung während t_{DEC} peak load during t_{DEC} charge de pointe pendant t_{DEC}	
Pos. 13	91	%	Spitzenauslastung im Betrieb peak load during operation charge de pointe pendant service	
Pos. 14	41	%	aktuelle Auslastung current load charge actuelle	
Pos. 15	100	%	aktuelle Ausgangsspannung current output voltage tension de sortie actuelle	

F-9

* J1 in Pos. 4f
** U_N = max. mögliche Ausgangsspannung
*** I_N = Gerätenennstrom

* J1 in pos. 4f
** U_N = max. output voltage
*** I_N = nominal output of the unit

//

Einstellbereich Setting range Domaine d'ajustage	Standardeinstellung Standard adjustment Adjustage standard	Auflösung Definition Solution
J2 in Pos.1f 0...90 Hz (max. 93 Hz) J2 in Pos.2f 0..180 Hz (max. 185 Hz) J2 in Pos.4f 0..360 Hz (max. 370 Hz)*		0,37 Hz 0,74 Hz 1,48 Hz
0 - 50 % U_N** bei f = 0 Hz	5 %	1 %
J2 in Pos.1f 23...90 Hz (max. 93 Hz) J2 in Pos.2f 47..180 Hz (max. 185 Hz) J2 in Pos.4f 94..360 Hz (max. 370 Hz)	50 Hz	1 Hz 1 Hz 1 Hz
$0 - \frac{f_{max.}}{2}$		
Pos. $\frac{f_{max.}}{2}$ .... $f_{max.}$	67 Hz	1 Hz
0,1...0,2...6,3 s / 0,1...1...2...63 s	10 s	1 s
0,1...0,2...6,3 s / 0,1...1...2...63 s	10 s	1 s
0 - 50 % U_N** bei f = 0 Hz	0 %	1 %
0,1; 0,2; 0,3...7,9 s	0,1 s	0,1 s
0...200 %, bezogen auf I_N*** 0...200 %, referred to I_N*** 0...200 %, référé à I_N***		1 %
0...200 %, bezogen auf I_N*** 0...200 %, referred to I_N*** 0...200 %, référé à I_N***		1 %
0...200 %, bezogen auf I_N*** 0...200 %, referred to I_N*** 0...200 %, référé à I_N***		1 %
0...200 %, bezogen auf I_N*** 0...200 %, referred to I_N*** 0...200 %, référé à I_N***		1 %
0...100 %, bezogen auf I_N*** 0...100 %, referred to I_N*** 0...100 %, référé à I_N***		1 %

T 3

* J1 in pos. 4f
** U_N = sortie de fréquence possible au maximum
*** I_N = courrant nominal de l'appareil

Wahlschalter S1 Select.switch S1 Commutateur S 1	Display Display Indication	Einheit Unit Unité	Bedeutung Sense Sens	Ursache Cause Cause	Abhilfe Remedy Remède
Pos. 0 - 15	OC	Over-current	Störung	Beschleunigungszeit zu kurz Motor überlastet	Beschleunigungszeit verlängern größeren Motor mit größerem KEB-COMBIVERT einsetzen
				Schalten zw. KEB-COMBIVERT und Motor	Reglerfreigabe erst durchführen, führen, wenn Motor zugeschaltet ist
				Kurzschluß	Kurzschluß beheben, Bauteile nach Betriebsanleitung überprüfen
				Erdschluß	Erdschluß beheben, Bauteile nach Betriebsanleitung überprüfen
				Sonstige Störungen	Bauteile nach Betriebsanleitung leitung überprüfen
			Fault	Acceleration time too short Motor overloaded	increase acceleration time use larger motor with larger KEB-COMBIVERT
				Switching between KEB-Combivert and motor	do not operate control release when the motor is not connected
				Short circuit	eliminate short circuit, check components according to instruction manual
				Ground fault	eliminate ground fault, check components according to instruction manual
				Other faults	check components according to instruction manual
			Défaut	Temps d'accélération trop court Surintensité	augmenter le temps d'accélération installer un moteur et un KEB-COMBIVERT plus puissant
				Commutation entre moteur moteur et le KEB-Combivert	dimensionner l'appareil en conséquence
				Court circuit	eliminer le court circuit. Vérifier les composants de puissance
				Mise à la terre	eliminer la mise à la terre Vérifier les composants de puissance
				autres perturbations	Vérifier les composants de puissance
Pos. 0 -15	OP	Over-Potential	Störung	Verzögerungszeit zu kurz	Verzögerungszeit verlängern, evtl. Bremsmodul einsetzen
				Netzspannung ist zu hoch	KEB-COMBIVERT an stabilisierte Netzspannung anschließen
				Energiereiche Spannungsspitzen*	Netzfilter vor COMBIVERT installieren, Bauteile nach Betriebsüberprüfen
			Fault	Deceleration time too short	increase deceleration time, use braking module if necessary
				Mains voltage too high	connect KEB-COMBIVERT to stabilized mains voltage
				Excessive voltage peaks*	install mains filters in series with KEB-COMBIVERT, check components according to instruction manual

* Wenn sich die Netzspannung plötzlich ändert, können die Schmelzsicherungen ansprechen. Abhilfe: Netzfilter einsetzen.

* If the mains voltage varies too suddenly, the main fuses installed in the unit may react. Remedy: Insert mains filters.

F-10

Wahlschalter S1 Select.switch S1 Commutateur S 1	Display Display Indication	Einheit Unit Unité	Bedeutung Sense Sens	Ursache Cause Cause	Abhilfe Remedy Remède
			Défaut	Temps de décélération trop court	augmenter le temps décélération, installer un module de freinage si nécessaire
				Tension secteur trop élevée	utiliser un régulateur de pour l'alimentation de la carte de commande
				Surtensions ou pics de tension*	installer un self en série avec le KEB-COMBIVERT Vérifier les composants de puissance
Pos. 0 - 15	OH	Over-Heat	Störung	Temperatursensor im KEB-COMBIVERT, Schaltschrank oder Motor hat angesprochen	Schaltschrankkühlung verbessern Luftfilter erneuern Motor mit Fremdlüftung ausstatten, ggf. größeren Motor einsetzen
			Fault	Thermal detector in the KEB-Combivert, control cabinet or motor has reacted	improve cooling of control cabinet replace air filters equip motor with forced cooling apply larger motor if necessary
			Défaut	Détecteur thermique installé dans KEB-Combivert, armoire ou motuer a réagi	perfectionner refroidissement de l'armoire remplacer filtre d'air munir moteur de ventilation forcée installer un moteur, plus puissant, les cas échéant

O P T I O N

Pos. 0 -15	GF GF	Ground-Fault	Störung	Erdschluß	Erdschluß beheben, Bauteile nach Betriebsanleitung überprüfen
			Fault	Ground fault	eliminate ground fault, ckeck components according to instruction manual
			Défaut	Mise à la terre	éliminer défaut de mise à la terre, vérifier les composants selon le manuel d'instruction

T 4

* Si la tension secteur change brutalement, les fusibles dans l'appareil peuvent réagir. Remède: Installer filtre de reseau.

Wahlschalter S1 Select.switch S1 Commutateur S 1	Display Display Indication	Einheit Unit Unitê	Bedeutung Sense Sens	Ursache Cause Cause	Abhilfe Remedy Remède
Pos. 0 - 15	nOP	no Operation	kein Betrieb no operation pas de service	keine Reglerfreigabe no control release pas d`activation variateur	ST mit COM verbinden Connect ST with COM Connecter ST à COM
Pos. 0/9/10	LS	Low Speed	Betrieb Operation Service	keine Drehrichtungsvorgabe no presetting of rotation sense pas de consigne du sens de rotation	F oder R mit COM ver-binden Connect F or R with C Connecter F ou R à CO
Pos. 0/9/10	37	Hz	Betrieb Operation Service	Ausgangsfrequenz = 37 Hz Output frequency = 37 Hz Fréquence de sortie = 37 Hz	
Pos. 0 - 15	UP	Under Potential	Störung	- Netzspannung zu niedrig - Phasenausfall	Spannungskonstanter v KEB-COMBIVERT installi-ren Netzschütze und Siche ungen überprüfen Bauteile nach Betriebs anleitung überprüfen
			Fault	- mains voltage too low - phase loss	install voltage regu-lator before the KEB-Combivert check mains relay and fuses, check component according to instructi manuel
			Défaut	- tension du réseau trop basse - microcoupure	installer stabilisateu de tension devant le KEB-COMBIVERT Vérifier les relais du réseau et fusibles Vérifier les composant selon le catalogue
Pos. 0 - 15	OL	Over- Load	Störung Fault Défaut	KEB-COMBIVERT überlastet (I x t - Funktion im Bereich von 111% - 200%) KEB-COMBIVERT overloaded (I x t - function in the range from 111% - 200%) KEB-COMBIVERT surchargé (I x t - fonction dans la gamme de 111% - 200%)	Gerät mind. 3 Minuten eingeschaltet lassen, bis "nOL" erscheint größeren Motor und größeren KEB-COMBIVER einsetzen Unit must be switched for 3 minutes at least till "nOL" appeares use larger motor and larger KEB-COMBIVERT l'appareil doit reste enclenché pour 3 minu au moins, jusqu'à ce c "nOL montre.
Pos. 0 - 15	nOL	no Over- Load	Gerät betriebs-bereit unit ready for operation appareil en ordre de marche	Abkühlphase nach "OL" ist abgelaufen, Betrieb ist wieder möglich cooling phase after "OL" is over, operation is possible again phase de refroidissement après "OL" est finie, opération est de nouveau possible	Gerät zurücksetzen du -RST mit COM verbinde -Gerät aus- und wiede einschalten Reset unit by -connecting RST with C -switching unit off a on again remettre l'appareil -en branchant RST ave COM -en déclenchant l'appareil

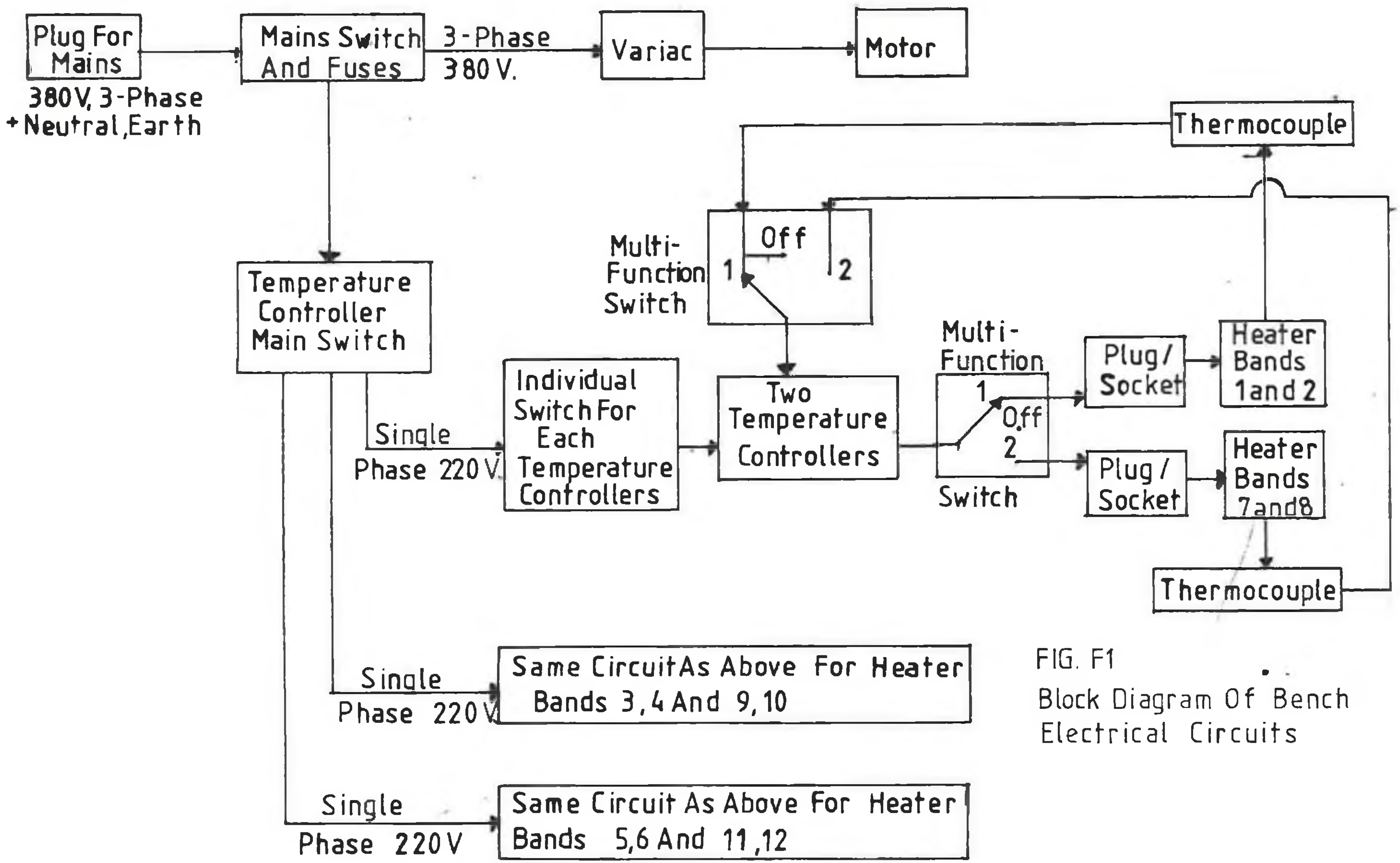


FIG. F1
Block Diagram Of Bench Electrical Circuits