DESIGN OF VACUUM COATING PLANT

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1974

Design of Vacuum Coating Plant

Diploma Project

Submitted in partial fulfilment of the requirements for the Postgraduate Diploma in Industrial Design

by

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Industrial Design Centre
Indian Institute of Technology
Bombay

1974

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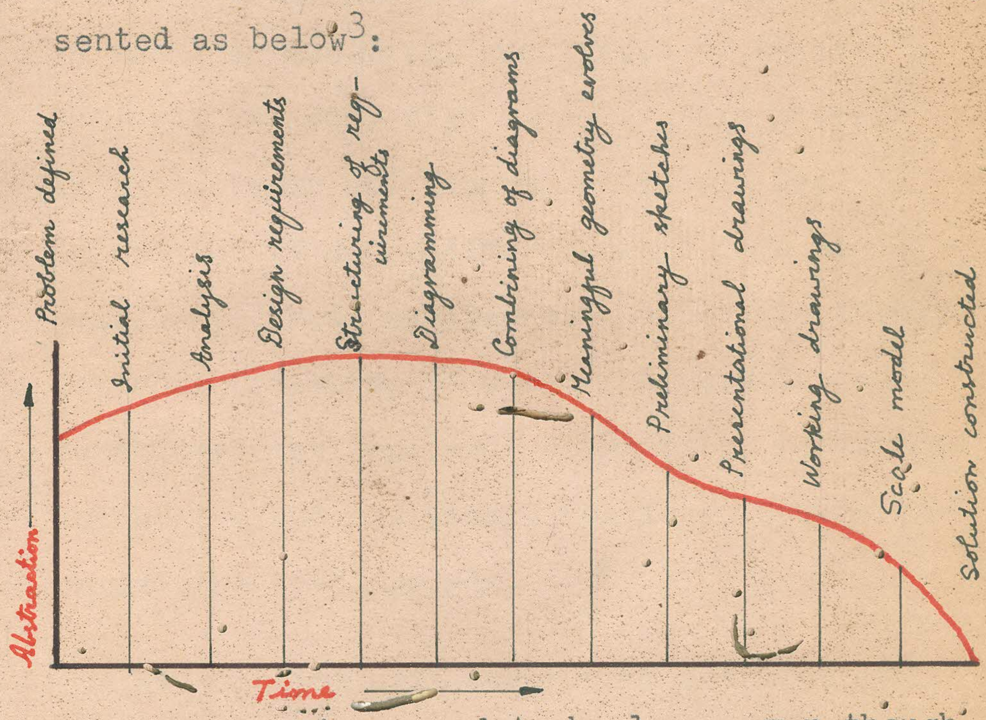
1.0 INTRODUCTION

Industrial design, relatively new discipline, is often misunderstood as a decorative design imparting importance only to the visual and formal qualities of a product. In fact, it is not merely a formal conception but rather the solution of a more complex problem. It does not accept the structure and mechanism as limits within which its solution must be developed[1]. An industrial designer's background in engineering, ergonomics, innovation, economy and aesthetics enables him to design a product which is most acceptable to the user as well as the producer.

In the design of heavy machineries and scientific equipments like vacuum coating plant, the innovative and human engineering aspects of industrial design can play a very significant role. In other words, it works with an intuitive sense of materials, for structure; for the economics of product use, maintenance and replacement; and for the organisation of elements into significant sensory patterns[2]. The whole design process which an industrial designer follows may be summed up and represented as below[3]:



The vacuum science and technology, even though relatively new, is a fullfledged branch of engineering today. The study of vacuum effects on materials, components or systems, alone or in combination with other environment has grown into a distinct technology during the past several years[4]. The major contribution to this branch has come from space technology which advanced spirally in the last few decades. Due to the short span of time that was available for the redesign of the whole vacuum evaporation unit, one could comprehend only the basic fundamentals of this technology. However, design decisions were taken in consultation with experts in the above discipline.

Vacuum coating is the process by which metals, semiconductors and dielectrics are deposited on metal or non-metal substrates by thermal evaporation under high vacuum. This process is extensively and economically used for deposition of decorative coatings such as jewellery, toys, appliances, automobile trims, low cost finishing of metal and plastics and functional coatings such as mirrors, reflectors, conductive and resistance coatings, corrosion resistance coatings etc.

The evaporation unit under consideration is meant for research laboratories and for small scale industries. With suitable modifications, the unit may also be used to carry out new deposition techniques like D.C. and R.F. sputtering.

In the redesign of the plant, endeavour was to effect improvements in the areas of :

- function
- structure
- material selection
- ergonomics
- cost reduction
- safety
- maintenance
- aesthetics and product graphics
- noise reduction and
- packaging

However, more weightage was attributed to function and human factors.

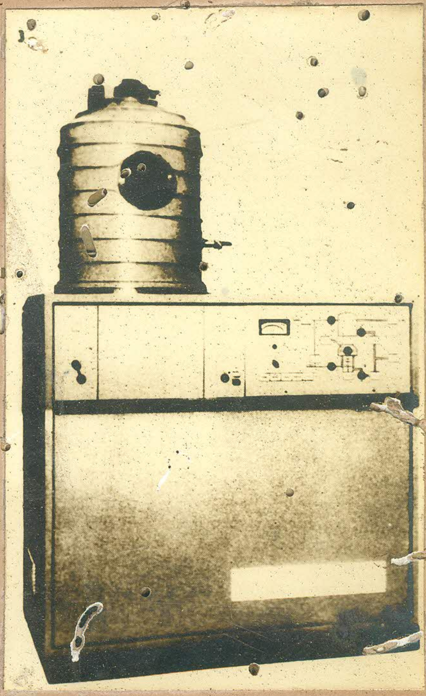
2.0 PROBLEM STATEMENT Redesign of 'Vacuum Coating Plant' to be used in research laboratories and in small scale industries.

INFORMATION

All possible data concerning the 'vacuum metalising unit', viz. various equipments available, manufacturing details, structural and functional informations, various users and their varied requirements, environment where it is used, latest developments in vacuum science and technology and such other related facts are furnished in this chapter.

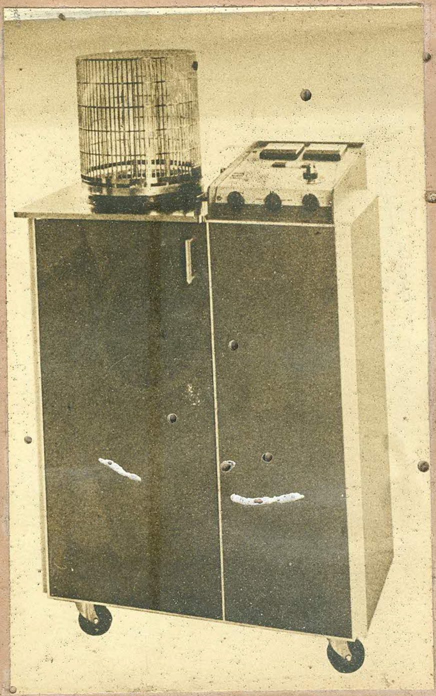
3.0 INFORMATION

3.1 Existing vacuum coating units

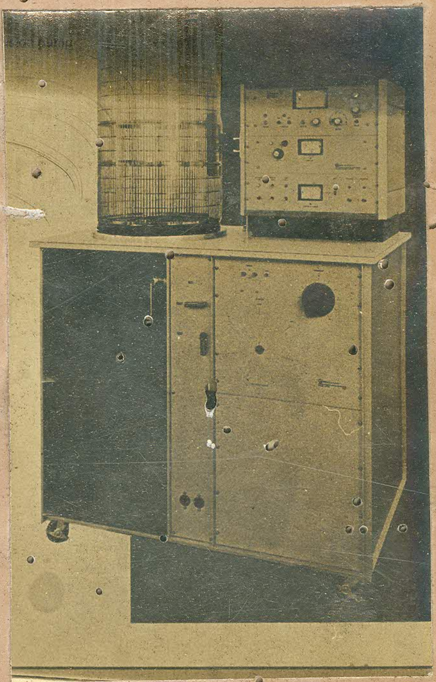


A Russian design

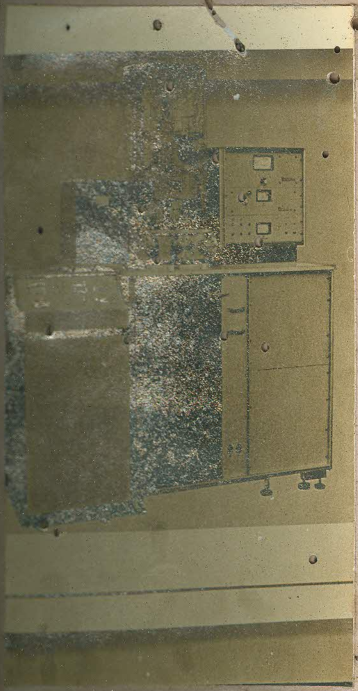
Unit manufactured by Varians, U.S.A.



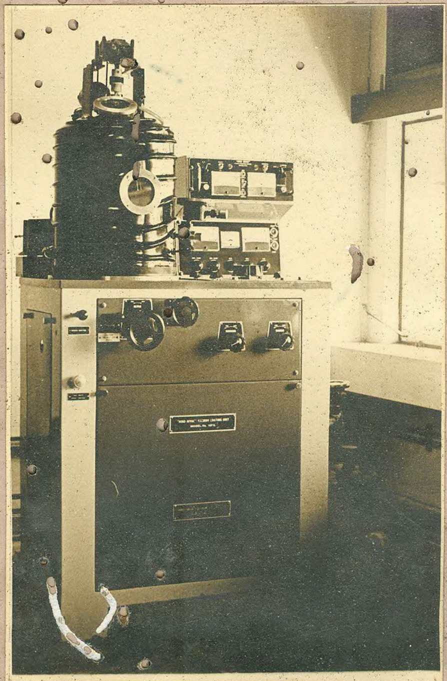
Another model by Varians



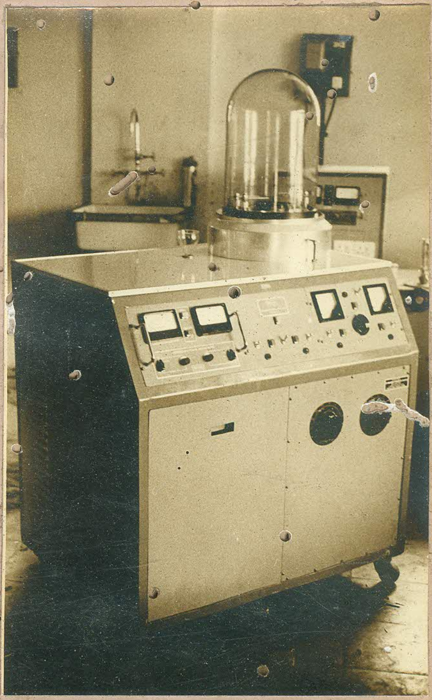
A flexible unit by Varians



Flexible unit with attachments for DC & RF sputtering

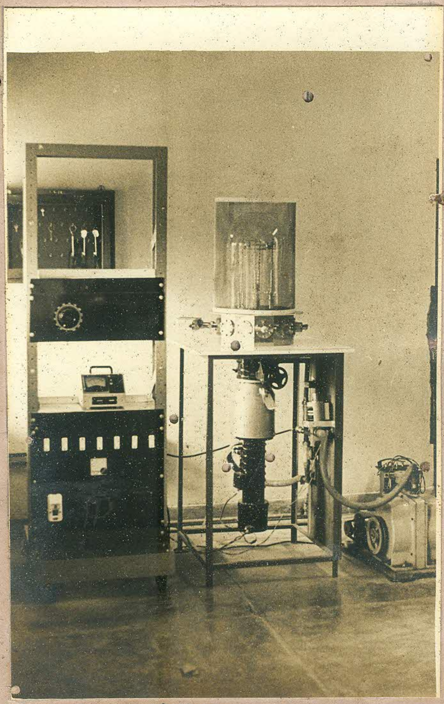


Unit manufactured by Hindhivac, Bangalore



Unit by Indo Burmah Petroleum

A B.A.R.C. model



A Laboratory assembled unit

Another laboratory assembled unit

3.2 Manufacturers : In India at present the leading manufacturers of this equipment are

1. Hindhivac, Bangalore and
2. I.B.P., Bombay.

The latter works in collaboration with B.A.R.C.

3.3 Users This model is largely used by research scholars, postgraduate and undergraduates to prepare high quality thin films of various materials for studying their electrical, magnetic, ionic and optical characteristics. It may also be used in small scale industries by ordinary personnel.

3.4 Principal parts of the unit

- Vacuum chamber or bell jar
- Substrate holder
- Source carrier or boats
- Substrate and source heaters
- Diffusion pump
- Rotary pump
- Liquid Nitrogen Trap
- Current Transformer
- Voltage Transformer
- Variacs
- Pressure gauges
- Ammeters

3.5 Normal operations involved

- Cleaning of substrates
- Cleaning the bell jar and other components of the vacuum chamber

- Loading the chamber with source and substrates
- Starting of the mechanical pump and the diffusion pump
- Operating the various valves like baffle valve, roughing valve and backing valve
- Switching on the heators and controlling the currents by means of the variacs

3.6 Requirements of the users

- Noiseless operation
- All components in one unit
- Operating the equipment in the sitting posture
- Leak-proof joints
- L.N. Traps for collecting moisture
- Stainless steel base plate
- Alarms to indicate the breakdown in water circulation, to show that the magnetic valve is working and to indicate the cut off of the power supply
- Movable type of unit
- Provision for fixing additional gauges to enable quick leak testing

3.7 Information on safety.

Five general categories can be listed to assist one in analysing a system for possible safety hazards. Each item should be considered from the point of view of operator safety as well as the prevention of equipment damage.

i. Electrical hazards

These include items such as proper electrical grounding (both A.C. and D.C.), high voltage leads, electrical feedthroughs, insulation breakdown, electrical fires, diffusion pump heators, gas discharges, magnet handling and use of R.F.

ii. Mechanical hazards

These include items like bell jar hoists, support of glass chambers, fore-pump drive belts, cooling fans, implosions, explosions, pressure relief valves, room for tightening metal flanges, torqueing mechanical valves etc.

iii. Chemical hazards

These include items like handling pump fluids, use of solvents, vacuum grease, chemical fires, vacuum properties of compounds (example - oxygen, beryllium, oxide ceramics).

iv. Cryogenic hazards

These includes such items as handling liquid nitrogen, transfering cryogenic liquids especially liquid helium, liquid oxygen and liquid hydrogen, Dewar breakage, use of cryogenic valves.

v. Thermal hazards

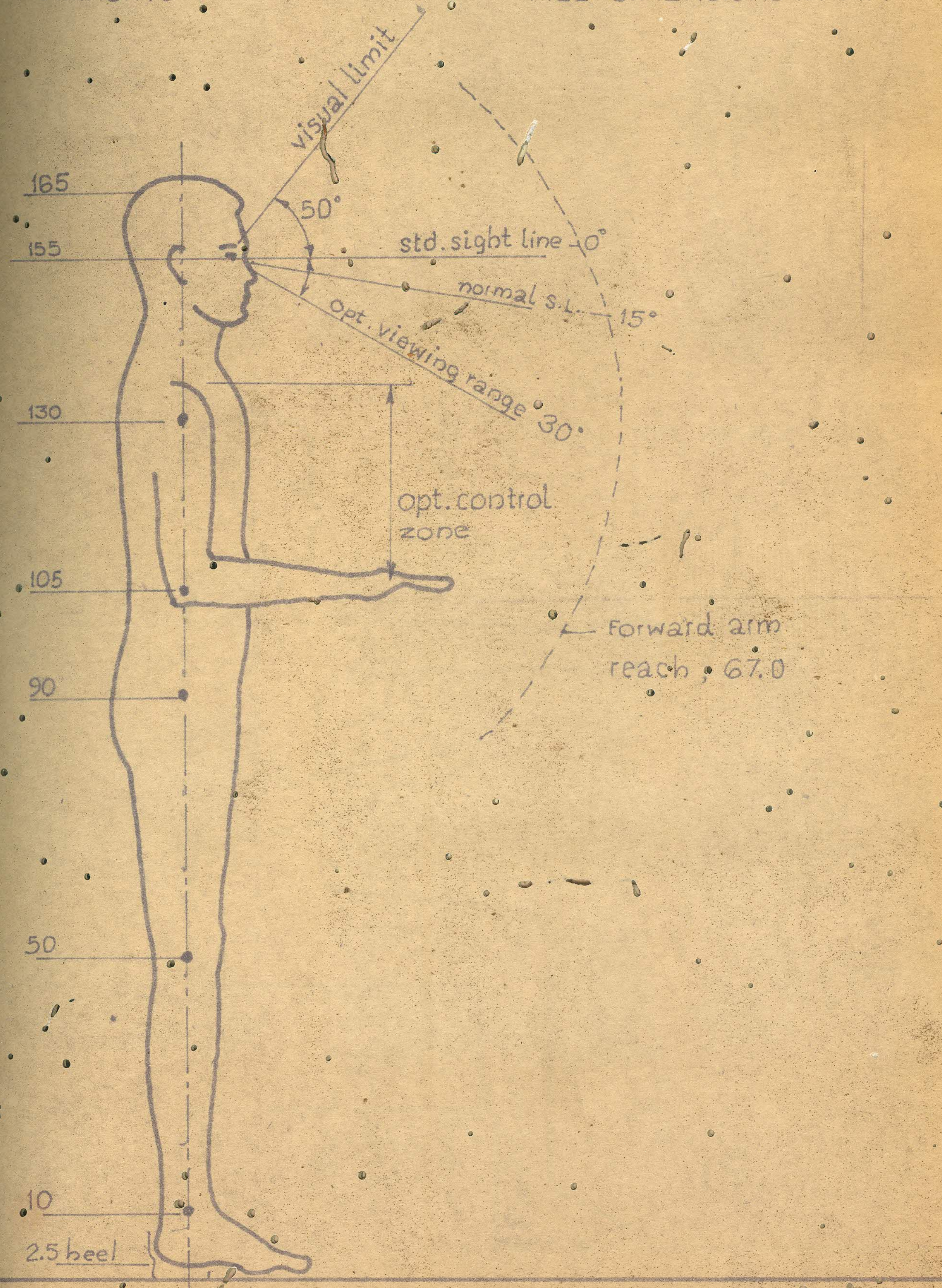
These include system bakeout, vacuum ovens, thermal stresses, high temperature cycling of material in vacuum systems.[5]

3.8 Developments in vacuum science	.	Diffusion pumps employing cold caps, fractionating tubes, silicone fluids of low vapour pressure[6,7].
	.	Butterfly valves replacing bellow sealed valves. They are clean and fast, have highest controlled conductance, low cost, reliability, simplicity of design and inexpensive maintenance[8].
	.	Use of high vacuum gauges[9]
	.	Use of thickness monitors
	.	Use of cheffron baffles
	.	Trivac vane pump, direct drive
	.	Flexible stainless tubings
3.9 Cost of the existing plants		Rs.85,000/- for the unit with metal bell jar lifted hydraulically.
		Rs.31,200/- for the unit with glass bell jar lifted manually.

ANTROPOMETRIC DATA – INDIAN ADULT MALE – 50% tile

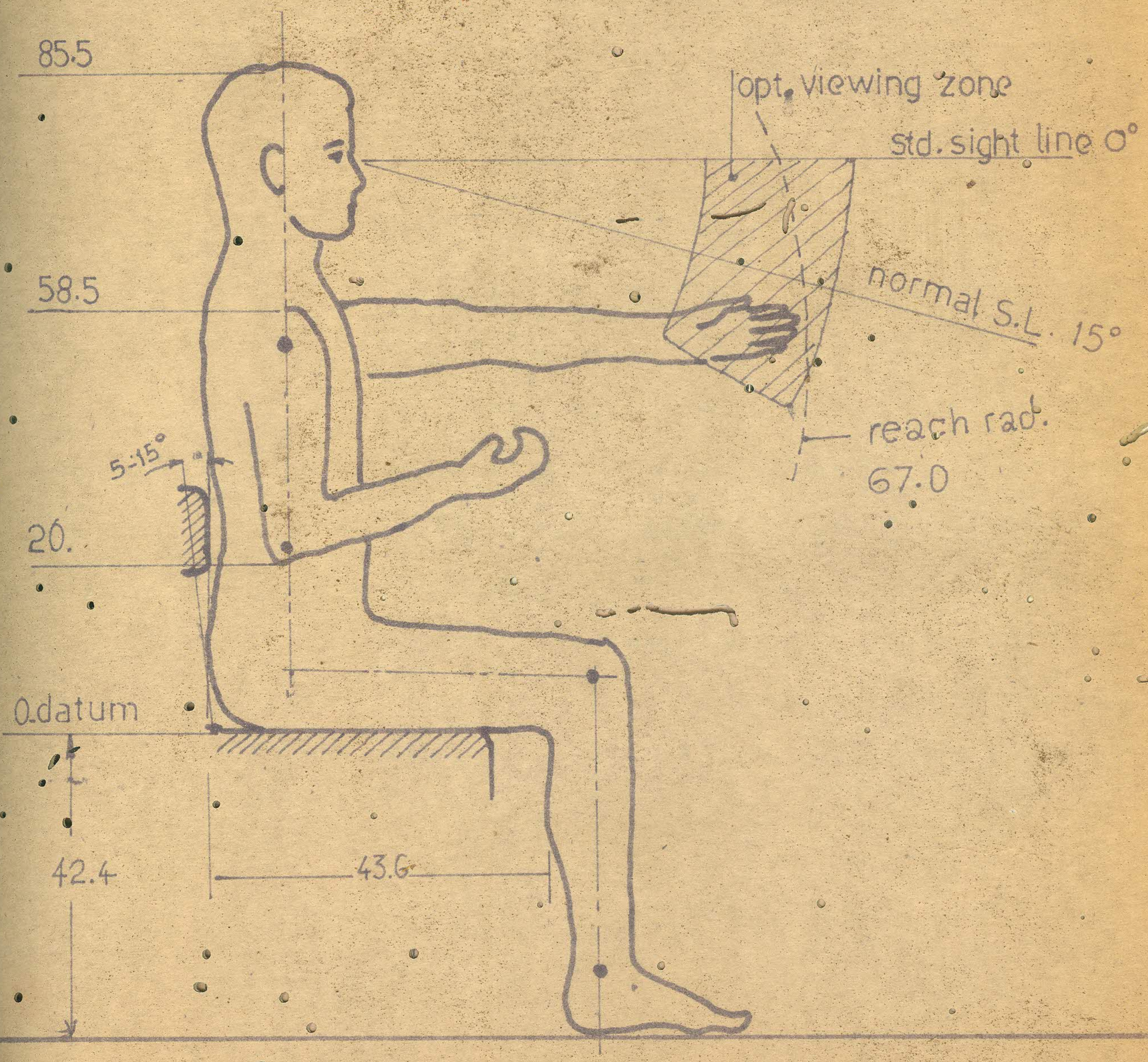
STANDING

ALL DIMENSIONS IN MM



ANTH. DATA

SITTING

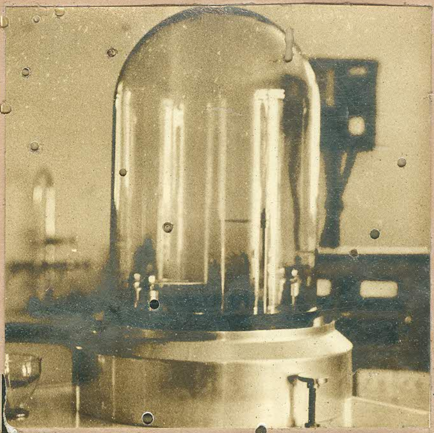


ANALYSIS

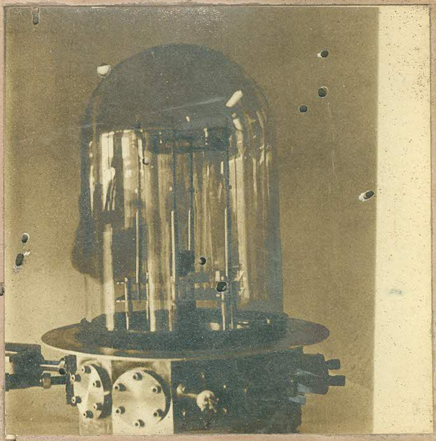
In design methodology analysis is regarded as the most important part. Analysis enables the designer to understand the problem to a greater depth, although the irrational and individual human needs can be comprehended by intuition. Analysis in essence comprises the following: structural, functional, ergonomical and safety, formal - visual and product graphics and value analysis. In this chapter the above analyses are dealt with in detail.

4.0 ANALYSIS

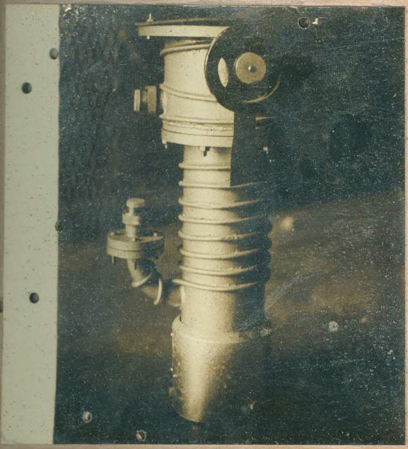
4.1 Structural



The glass bell jar inside which the source and substrates are located is connected to diffusion pump through the baffle valve. Dim.300mm Ø 450mm ht

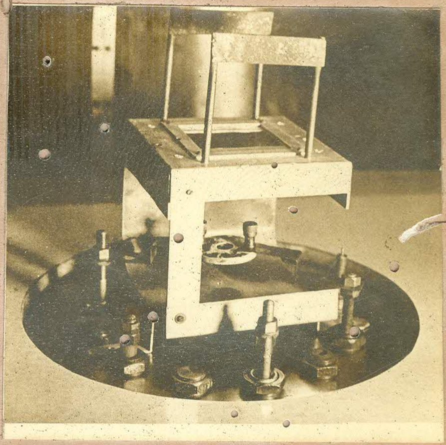


Bell jar and base plate with electrical connections from sides. Base plate is made of stainless steel.

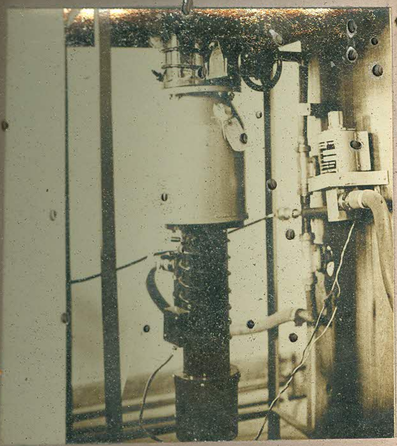


Diffusion pump with baffle valve.

Base plate with electrical connections from below, has 12 holes and the central opening. This weakens the plate and so thick plate has to be used.



Base plate with substrate holder.



Diffusion pump with liquid nitrogen trap. On the right of the pump is the magnetic valve. Dia 200 mm

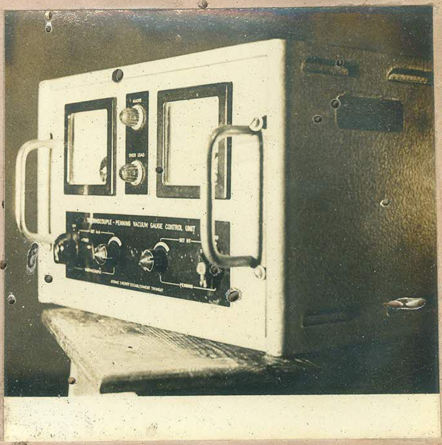
Ht. 850 mm

Rotary pump and motor.

Ht. 440 mm

Length 600 mm

Depth 300 mm

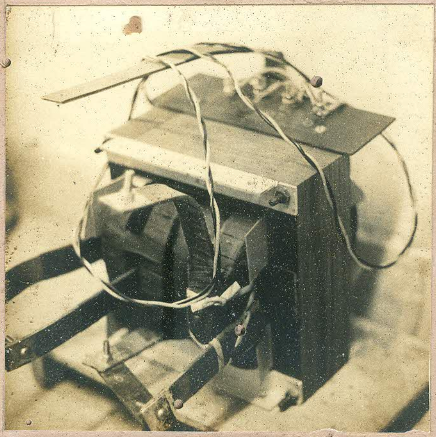


Vacuum measuring instrument. Size and weight can be reduced by proper layout and material selection.

385 mm W, 240 mm H

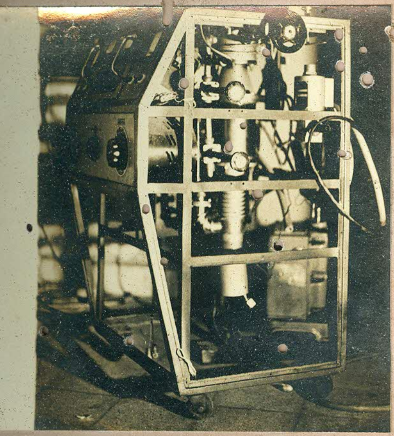
260 mm D.

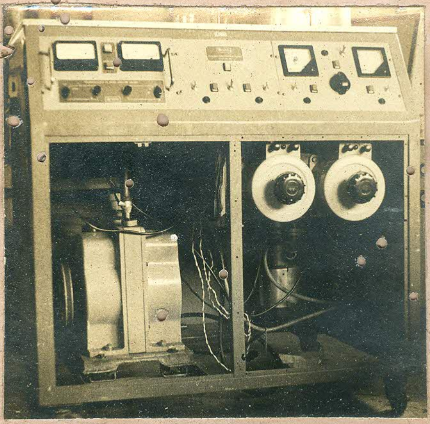
Inside details of the vacuum measuring instrument.

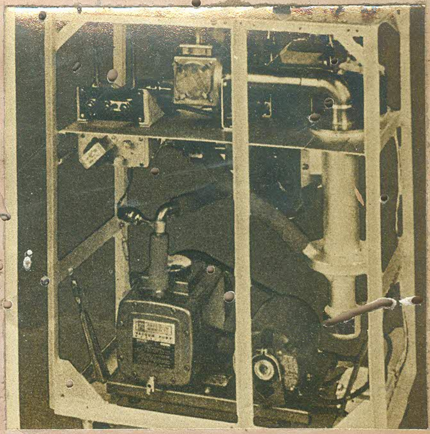


Low Tension and High Tension transformers.

Dim. 220 mm cube







All the above components are assembled on a frame-work without imparting much consideration to the user's convenience and easy maintenance. The framework is fabricated by welding angles together. The panels are of sheet metal and screwed to the frame. The size of the unit can be reduced if the elements are properly laid out. The diffusion pump is not supported and this becomes a problem during transportation.

Dimensions: 1000mm W, 930mm H, 750 mm D.

4.2 Functional

4.2.1 Vacuum chamber

Function of vacuum chamber is to isolate the substrate and source from atmosphere. In the glass bell jar it is possible to see the inside components during operation. In the metal bell jar a glass window is provided. Duration operation the operator should be safe from implosion or explosion. In the ordinary plants no provision is provided for lifting the bell jar easily. In the case of metal bell jar it is cooled by circulating water.

4.2.2 Substrate holder

It holds one or two substrates at a time. The substrate some times falls down when the bell jar is being placed back. Placing the substrate is difficult and consumes a lot of time. The holder is not movable.

4.2.3 Source holder or boat

Maximum number of sources which can be accommodated are two. Tightening and loosening the nuts of the holder consumes time.

4.2.4 Shield and shutter

The function of the shield is to prevent coating of the bell jar with the evaporated material. The function of the shutter is to stopthe coating process.

4.2.5 Diffusion pump

The function is to create ultimate vacuum. It starts working from 10^{-2} torr or 10^{-3} torr. Even though L.N.T. is present, very few use it. Above the diffusion pump no baffles are provided. The pumpdown time is high.

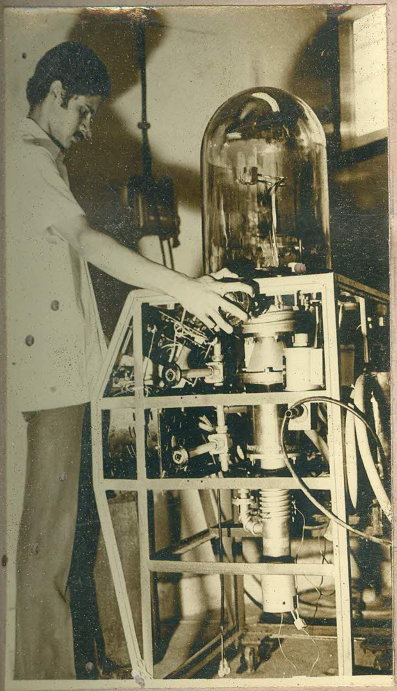
4.2.6 Rotary pump

The function is to obtain the initial back pressure of 10^{-2} or 10^{-3} torr. When the diffusion pump starts working, this pump works as a backing pump. The pumpdown time is high. It operates with prohibitive noise.

4.2.10 Liquid nitrogen trap

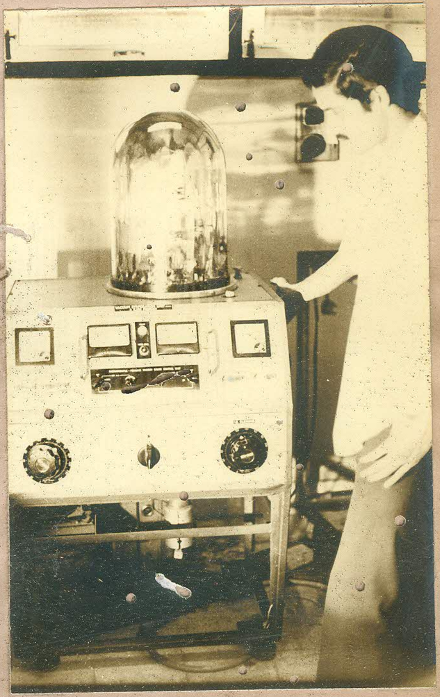
Its function is to prevent back streaming, thereby reducing the pumpdown time. But it reduces conductance considerably when the height is more. Very few operators take advantage of this due to unavailability of liquid nitrogen and difficulty in its storage.

4.3 Ergonomical and safety analysis



The operator has to stand and operate for more than one hour to complete the cycle of operation.

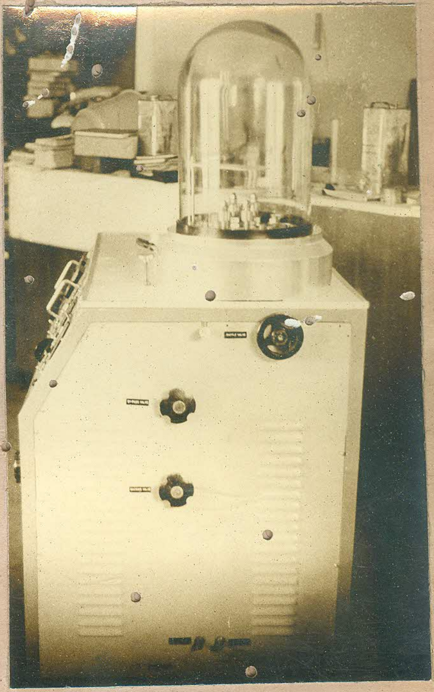
For manipulating the different controls the operator has to bend down. This is very painful.



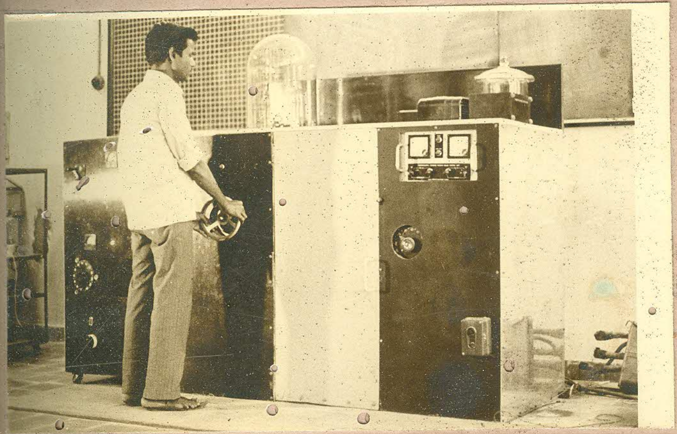
Reading of meters and operating the controls simultaneously is difficult.

For reading the meters the operator has to look down always. Also close reading is not possible.

Controlling the current by adjusting the variac and watching the inside of the chamber simultaneously is difficult.



The heights and locations of the control knobs are not convenient to the operator. The size and shape of the knobs are not proper for comfortable operation.



The height of the operator and the height of the unit are not compatible which results in inconvenience.

The layout of meters and the related controls is not easily comprehensible. The heights at which they are located are incorrect from the point of view of ergonomics.

Difficulty in lifting the bell jar can be understood obviously from the illustration. Replacing the bell jar is still more difficult and precarious.

- No facilities are provided for loading and unloading the substrate or the source
- No facilities are present to keep the bell jar during the loading time
- Leak testing consumes considerable time
- Maintenance is difficult because of the inaccessible components
- No provision is offered to reduce the noise generated by the rotary pump during working

4.4 Value analysis[10]

It is a systematic and analytical technique used to examine all the functions of an existing item, product, product system or activity in order to determine if a cost item can be reduced while maintaining or improving the functional requirements.

The types of value are - use value, cost value, exchange value and esteem value.
Value is the ratio of function to cost.
Use value is the lowest cost required to achieve a given use or service.
Esteem value is the lowest cost required to achieve a given desirability.
Cost value is the sum of material, labour and other costs required to produce article. It also includes cost of distribution.
Exchange value is the market value which enables us to exchange an article for another article or for money.

Use value, exchange value and esteem value of the existing evaporation unit are obviously very low. Cost value analysis is not performed due to lack of time and facilities.

4.5 Formal - Visual analysis

It is to examine validity and integration of formal elements, visual and psychological functions of colour, shape and product graphics. The natural desire of man while looking at a random pattern is to create order or to see order in parts in relation to the whole. But again, too much order and lack of variety is also unwanted.

The colour of some of the existing equipments is dark blue with few parts in black. This is the colour usually given for machineries. This colour is dull and in the research laboratories it is not at all suitable. The overall form of the equipment is a rectangular cube. Even though this is a simple form, the organisation of the various elements has no order.

Product graphics is ineffectively sited. Its location, size, colour and shape are of much significance because it projects the image and identity of a corporation.

HYPOTHESIS

The process of analysis leads one to certain conclusions and will be in a position to discover exact design requirements that are indispensable for the satisfactory and successful functioning of the product. In the chapter hypothesis the above requirements are enumerated under various headings like structural, functional, ergonomical and safety, formal - visual and product graphics.

5.0 HYPOTHESIS

5.1.1

5.1 Structural

- The layout of the various components should be such that the loss of space is minimum; the accessibility being retained.
- The overall dimensions are decided by taking into consideration the human factors.
- Material selection should be such that it is structurally strong, light in weight and functional.
- Fabrication must be easy, quick and less expensive.
- The vibration caused by the mechanical pump should be minimum.
- Diffusion pump should be fastened to the framework strongly, but not receiving the vibration from the mechanical pump.

5.2 Functional

- The vacuum chamber should be versatile to accommodate more number of substrate and coat them simultaneously if required.
- There should be provision for placing more number of sources also.
- The diffusion pump and mechanical pump should be incorporated with the latest developments in the particular field.
- Butterfly valves should be preferred to bellow sealed valves because of their advantages mentioned before.

- The unit should be movable along with all components.
- In order to facilitate leak testing there should be provision for fixing gauges at different points.
- Gauge head should be carefully sited and correctly used to get accurate results.
- Thickness monitors are to be present with the unit for controlling the thickness.

5.3 Ergonomical and safety

- The equipment should have facilities to sit and perform the various operations.
- Loading and unloading of the substrates and sources should be easy and less time consuming.
- The height and location of control console should be decided on the basis of anthropometric data.[11,12,13,14]
- The size, shape and contour of the knobs, cranks and other controls should be arrived at on the basis of human engineering data.[15]
- The dial layout should be designed in such a way that check reading or quantitative reading is optimum.[16,17,18]
- The pointer should also be designed for easy reading.[19]
- The noise level of the equipment should be in the safe limit.

- It should be possible to open and close the enclosure panels quickly so that leak testing and maintenance is convenient and less time consuming.
- All safety measures should be incorporated in the equipment to prevent damage, and danger to the operator.

5.4 Formal, visual & Product graphics

- Functional colours should be selected for the different elements.
- Colour selected should go in harmony with the environment where the product will be installed.
- Organisation of the various elements should evince order, balance and proportion.
- There should be economy of planes and forms.
- Form should be decided in harmony with the qualities of the material selected.
- Disturbing elements like screw heads, weld marks etc. should be minimum.
- Product graphics should be effectively located.

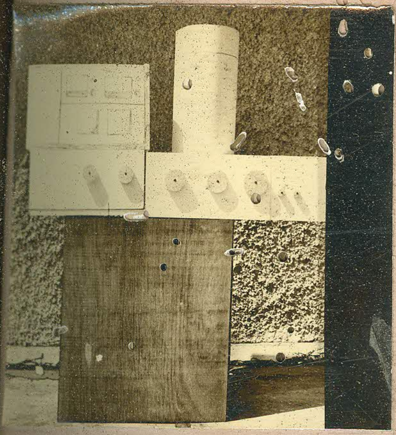
SYNTHESIS AND SOLUTION

This chapter consists of synthesis, alternative solutions and the final solution. During the synthetic phase one tries to arrive at solutions - evolutionary or innovative - which can satisfy the various design requirements or constraints some of which, however, may be optimised. Rough models and mock-up models are constructed and studied to find out any shortcomings in the design solution. By effecting suitable omissions and commissions, one decides about the final solution. The details of the final solution is worked out, model fabricated and drawings made to communicate the design concept.

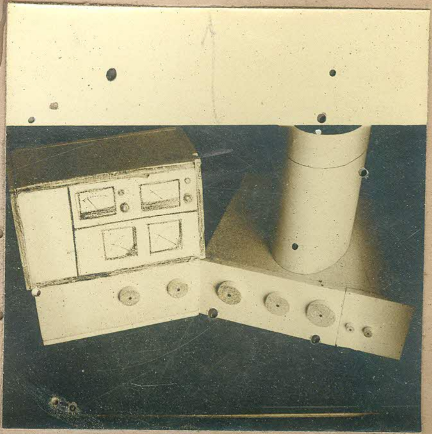
6.0 SYNTHESIS

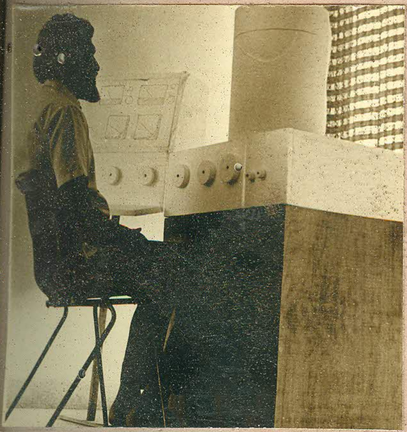
As mentioned before, convenience and comfort to the operator, versatility of the equipment and ordered organisation of the various elements were the factors optimised. Nevertheless all possible efforts were made to impart due consideration to other requirements also viz. ease of fabrication, ease of maintenance, proper material selection, cost etc.

With the above constraints in mind, design solution was arrived at. During the synthetic phase many preliminary sketches, rough models in cardboard, full scale mock-up models to validate human factors and plaster models to decide about the final form were made.



Mock-up model made to decide optimum dimensions and locations of different controls and displays.



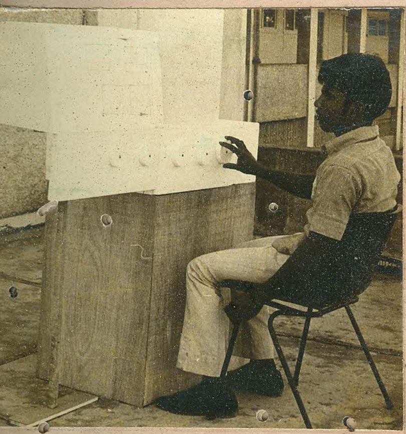


Judging the compatibility between operator height and equipment height.

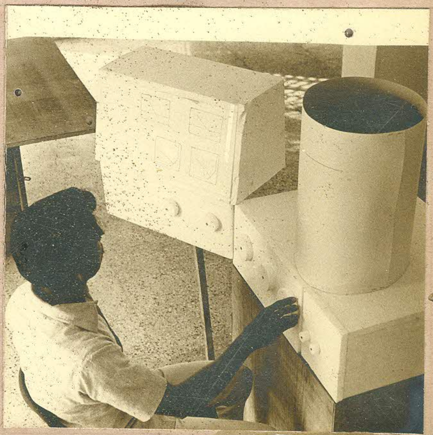
A tall operator working on the equipment.

Operator of medium height working on the equipment.

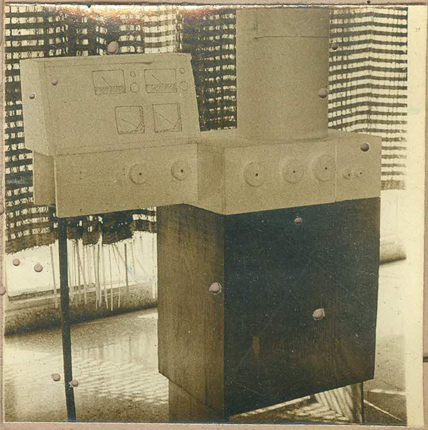
Operator of short stature working on the equipment.

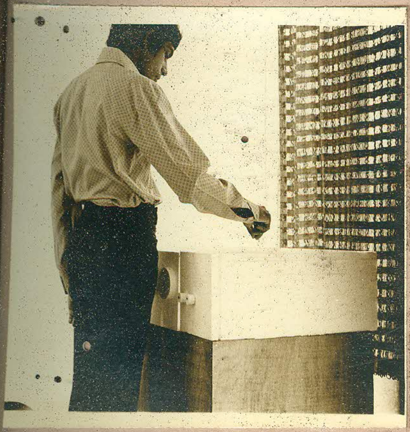


Operator of short stature working on the equipment in sitting posture.



A short operator manipulating controls in the standing posture. The equipment height was increased.



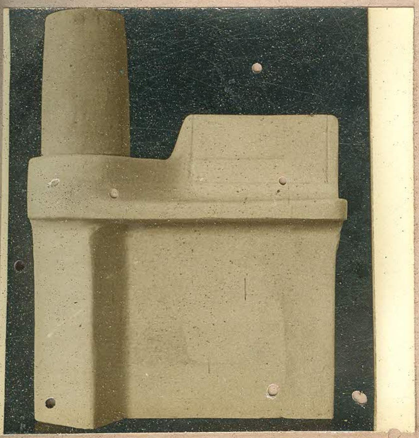


< Operator of average height is loading the vacuum chamber.

He operates the switches. >

< He is operating the various valves.

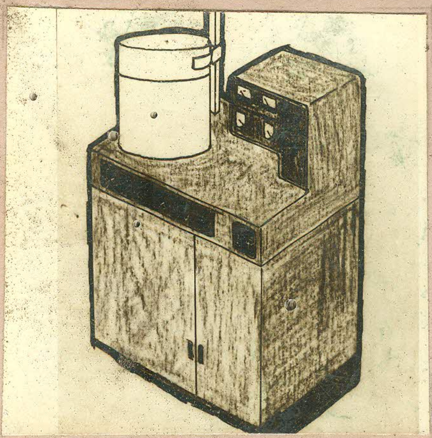
He is waiting to reach the required vacuum, resting on the working surface. >

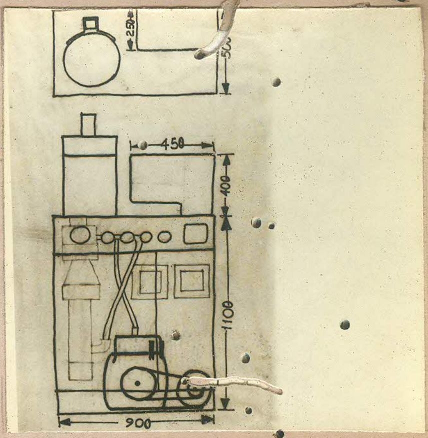


The final shape of the unit was arrived at by trying various forms in plaster.

7.0 ALTERNATIVE SOLUTIONS

7.1 Solution 1



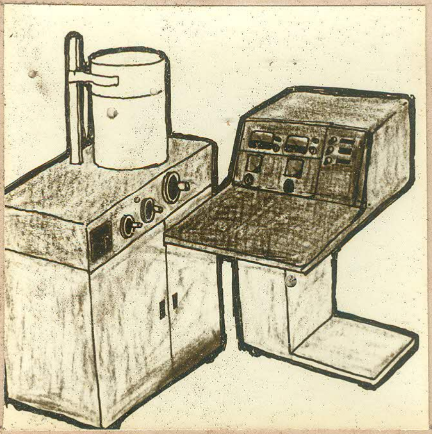


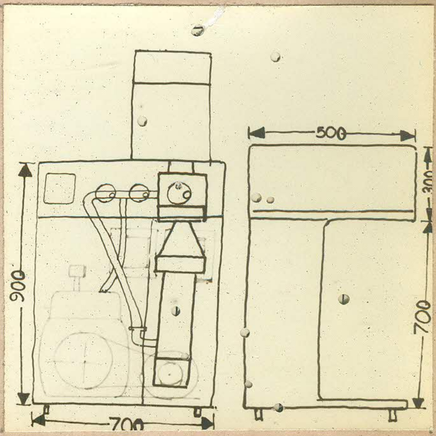
This unit is designed for standing operations. The various controls are placed at such a height that they can be operated conveniently, comfortably and quickly.

The vacuum chamber is designed for maximum versatility and flexibility. The details are furnished along with the final solution.

The control console is located at the optimum height for accurate and quick recording of the various informations.
The whole equipment is fabricated in sheet metal and is movable.

7.2 Solution 2

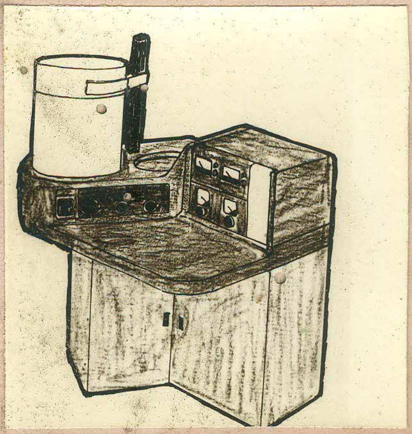


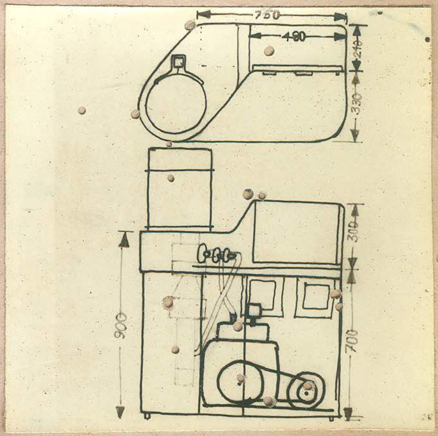


The unit is designed for operating in the sitting posture. The control console forms one unit and the vacuum chamber and pumps form another unit so that they can be transported easily and arranged according to the requirements of the operator.

The height of the controls, the height of the working/writing area and display height are decided on the basis of anthropometrical data. The vacuum chamber is versatile and flexible as in the previous case.
The control console is in FRP and the other unit is in sheet metal.

7.4 Solution 4





In this case also the operations are to be carried out in the sitting posture.
The overall dimensions of ~~the~~ equipment, placement of the various controls, knobs and displays and the layout of the various elements inside the equipment are decided for obtaining optimum results.

The salient feature of this design is the use of FRP for the top portion of the equipment, because of its unique qualities.
Other advantages of this design are same as that of the previous ones.

8.0 FINAL SOLUTION

From the alternative solutions the last solution is chosen as the final solution. The details of this solution is given below.

The dimensions of the equipment are decided for operation in the sitting posture. Working/writing surface which is a part of the equipment itself is provided as seen in the illustration.

The vacuum chamber is designed for maximum flexibility. The substrate holder can accommodate eight substrates at a time. The substrates can be slided in for loading the chamber, thereby reducing the time and effort. The substrate holder is movable.

Eight number of sources may be placed, thus increasing the flexibility. The source holder is rotatable as required by the operator.

electrical and thermal insulation properties
(6) Best material for batch production
(7) No further finishing required after mould-
ing.

Handwheels are supplanted with cranks to facilitate opening and closing of the valves. The knobs of the variacs are redesigned for better grip and comfort.

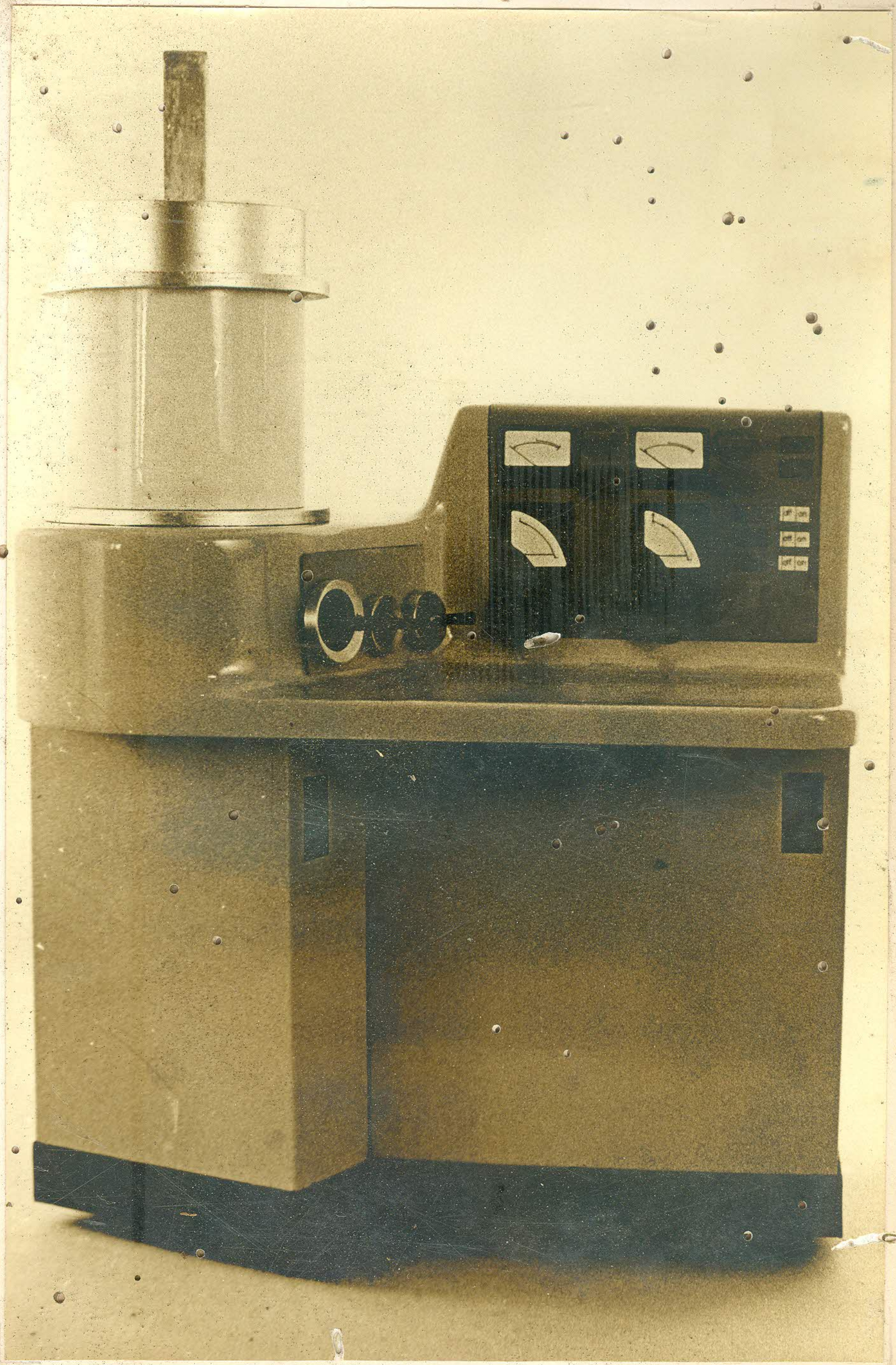
The dials, graduations, pointer, the colour of the dial and the overall shape of the meter are arrived at on the basis of ergonomics and perceptive psychology.

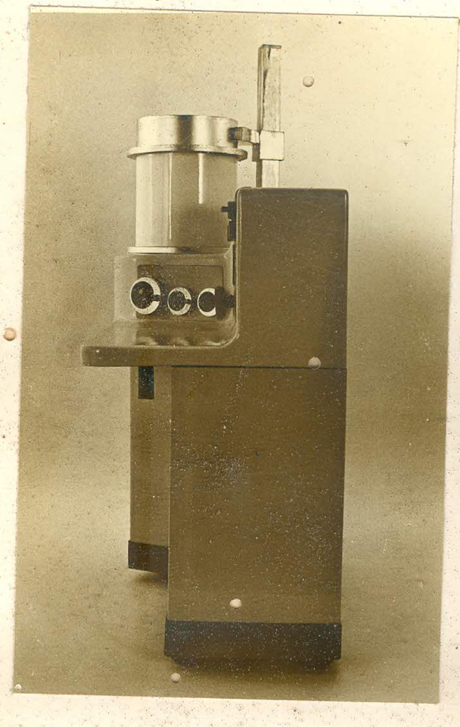
For ease of maintenance and leak testing, the enclosure panels are so designed that they can be slided out for opening.

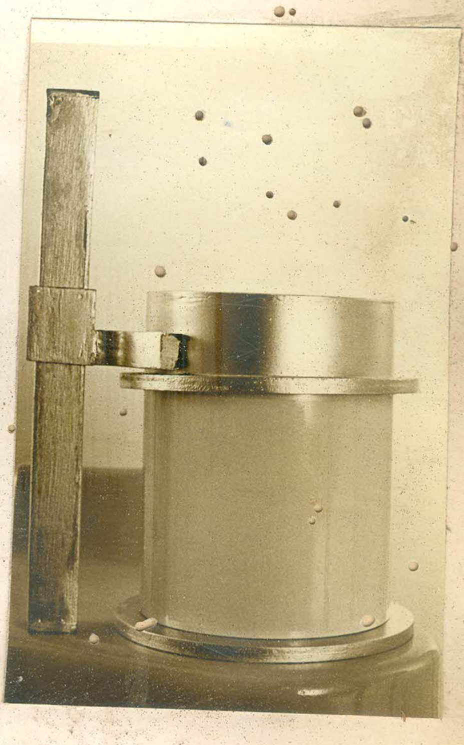
- The colour scheme of the unit is functional and selected to suit the environment of research laboratories or industries.

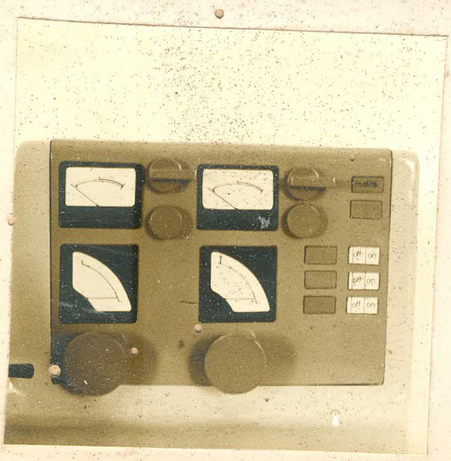
- Provision to keep the glass cylinder during the loading time is present in the redesigned plant.

- The total appearance of the redesigned plant has been arrived at for imparting order, balance and proportion to the various elements contained in the unit.





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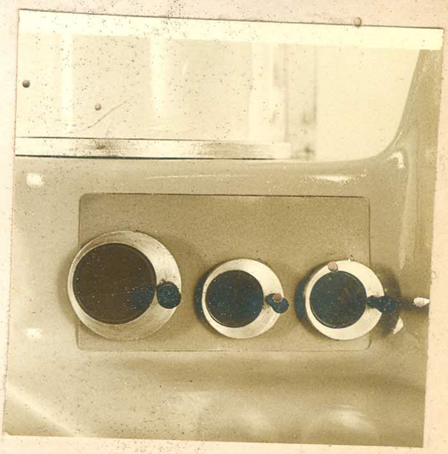

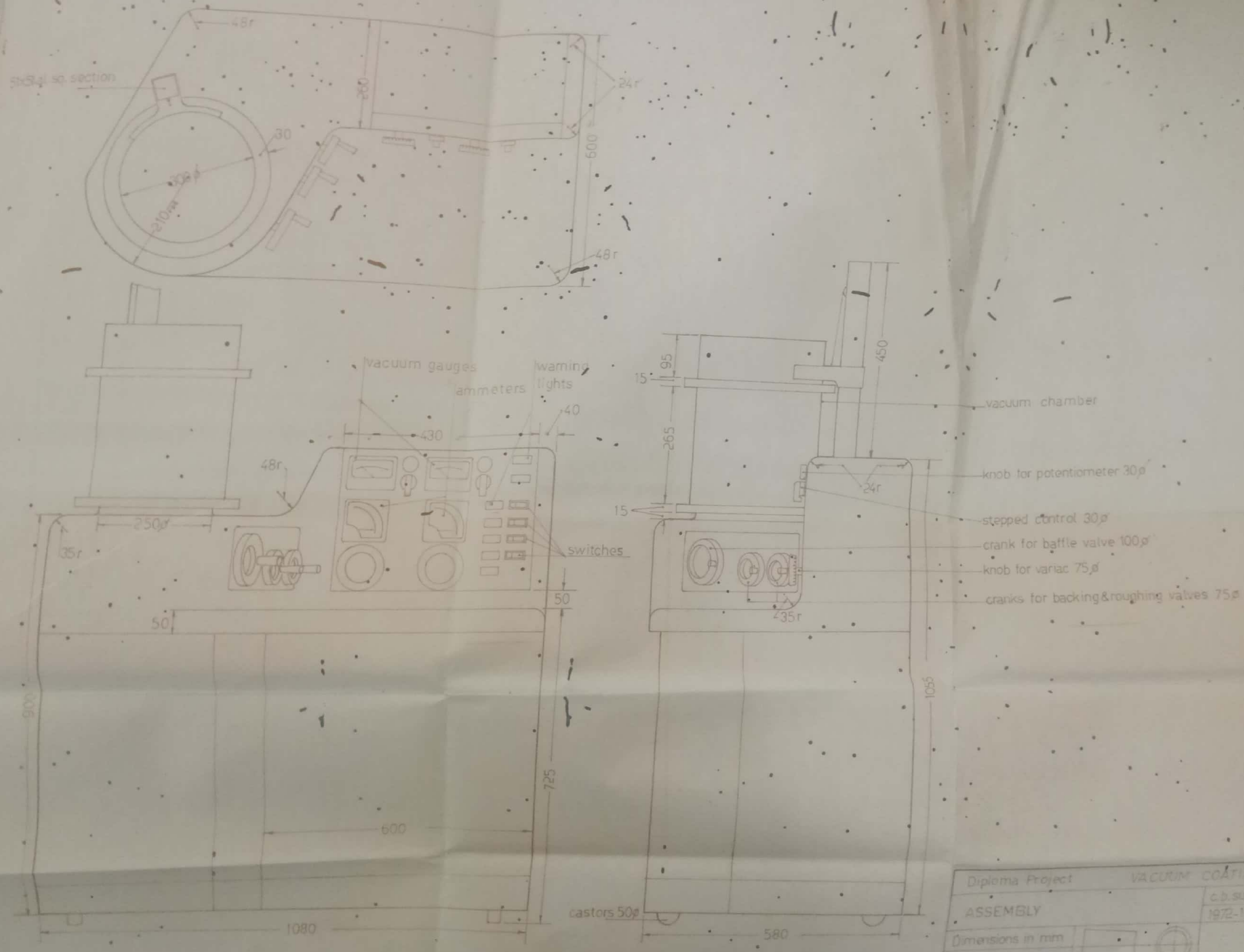

Diploma Project — VACUUM COATING PLANT

c.b.suresh babu — F 923

ASSEMBLY — 1972-1974 — fourth batch

Dimensions in mm

scale 1:6

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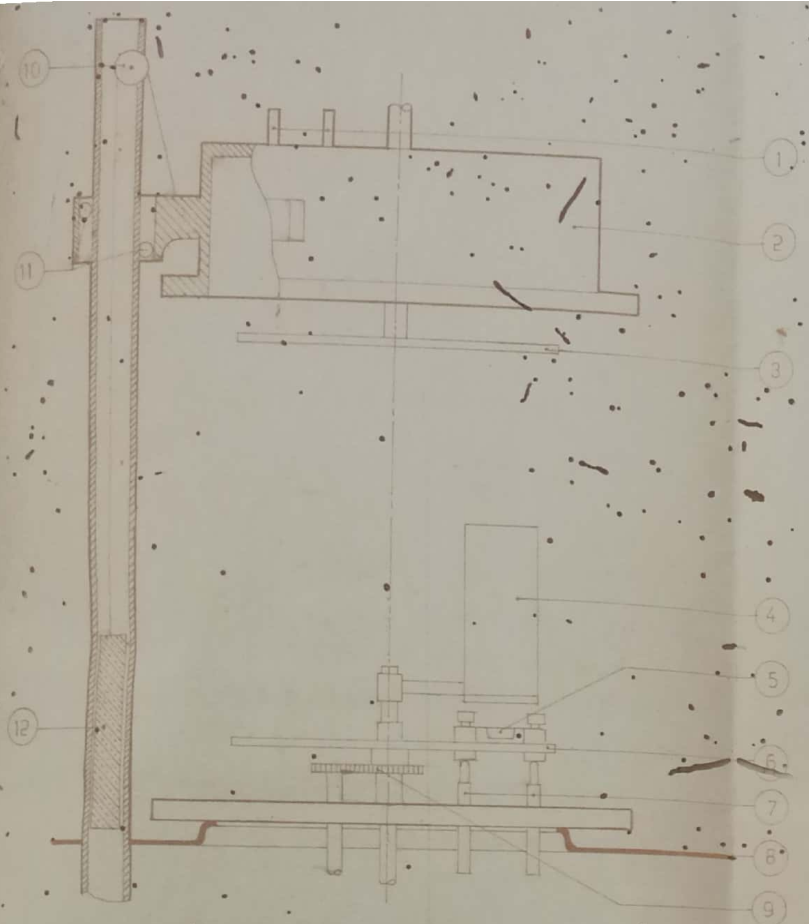

DETAILS OF VACUUM CHAMBER &

LIFTING MECHANISM

s.no	description	material	no. off	finish
12	counter weight	lead		mould
11	rollers	st.steel		m/c
10	pulley	brass	1	"
9	gears	st steel	2	m/c
8	frp top			mould
7	source heater leads	copper	2	
6	source holder	st.steel	1	"
5	boat	molybdenum		
4	shutter cum shield	"	1	"
3	sub. holder	"	1	"
2	chamber top	st.steel	1	"
1	substrate heater leads	copper	2	m/c

Diploma project	VACUUM COATING PLANT	
CHAMBER	c b suresh babu	F.923
	1972-1974	fourth batch

INDUSTRIAL • DESIGN CENTRE I.I.T., BOMBAY-76

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