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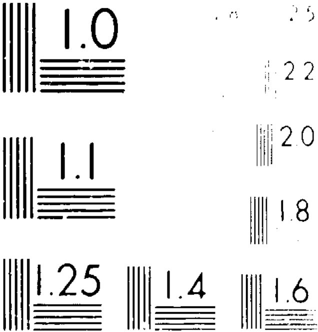
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LOCAL MANUFACTURING OF WATERTURBINES*

by

Markus Eisenring**

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1. Introduction

When discussing local turbine manufacturing it must be pointed out first, that it is impossible to discuss this theme in a way, which is valid for all countries. Parameters, like standard of industrialisation and electrification, purpose of installing turbines, have to be considered and differ very much from country to country. Factors like these will influence the approach to turbine installations and the implementation may be different. Very often the role of water power is misunderstood and underestimated. Also the requirements for labour, workmanship and engineering and the expenses are underrated.

The way of production and implementation is of course linked to the needs and possibilities of each country. The crucial points are to determine the needs and possibilities and to get the corresponding designs. Industrialised countries are in possession of all the know-how and manufacturing facilities. However they are reluctant to provide their services for different reasons.

Their prices are high because of high technology and standards, complete automatisation of turbine installations, expensive labour, mechanised fabrication and because of high overhead costs. On the other hand less industrialised countries should be encouraged just by these facts to start their own local turbine manufacturing. First of all their manufacturing possibilities are sometimes limited and their standards and requirements are different. But by using appropriate designs and manufacturing methods costs can be reduced considerably. Expensive machines like rack cleaning devices, full automatisation of the power plants and sometimes even complicated mechanical governors can be avoided already in the design stage. Labour costs are often low, which reduces costs for production, service and maintenance. In certain cases a power plant can be operated by hand, which reduces the initial costs drastically.

2. Ecological and Economical Aspects

Waterpower is one of the cleanest power sources. However the encroachment on nature must be minimised. Careful planning and construction of power plants can help to preserve nature and forest. Plants can also be incorporated in checkdams and flood control systems.
Nowadays the opinion is still prevailing that the role of small hydro power is unimportant and that mini hydro generation is not economic. Representative values for investment costs per kilowatthour for large run-of-river power plants are 0.03 to 0.05 US $ / kWh. For small hydro generation units, where just big plants have been scaled down, costs are the same or higher. But it has been proven that reliable small hydro generation units can be built with investment costs smaller than 0.02 US $ / kWh and thus run economically. In addition locally manufactured turbines save foreign currency and create employment.
Please refer to the manual "Local Experience with Micro Hydro Technology" for more information on this subject (*).

3. Low Cost Design Specifications for Small Power Plants

All power plant components like diversion dam, intake, desilting basin, screens, conduit system, penstock, electromechanical equipment, governor, electrical distribution etc must be carefully designed to achieve minimal costs and still maintain reliability.
Semipermanent intake structures may be considered. Rack installations must not necessarily be self cleaning. Open canals are in most cases more economic than low pressure pipes as conduit systems. Penstock pipes must not be designed like in most big power plants, so production is cheaper, handling easier and manufacturing by small workshops is possible.

(*) Manual is available at SKAT

The specifications for the machinery should be corresponding to lowered standards. For locally manufactured turbines economics are more important than high live expectancy and efficiency.
In many cases direct mechanical power supply to the end user is possible. This makes the powerplant simpler and gives a better efficiency at reduced costs. Mechanical governors can be omitted, if the plant is supplying electricity to the grid.
Even industrialised countries have started to rebuild and modernise their old small power plants, which had been neglected for decades. However, an economic reconstruction is only possible by downscaling the sophisticated technology of large power stations. Even these countries have to learn how to reconstruct, renew and optimise small power plants in a new, indigenous but simple manner. New solutions have to be found in order not just to copy large power plants on a smaller scale.
One has to make up one's mind on these subjects before starting local turbine manufacturing, because it doesn't make sense to have locally made turbines and on the other hand sophisticated and overdimensioned components of an installation.

4. Requirements for Local Turbine Manufacturing

Before setting out to install small hydro generation units, one has to consider several things, such as:

- implementing institution
- financial sources and potential
- energy needs
- hydro potential
- suitable location
- mechanical and/or electrical energy production
- requirements for infrastructure, engineering, machinery, operation, maintenance etc.
- future expenses involved in the project

Besides time, effort and expenses, social, cultural, environmental and economic factors must be considered to decide on local turbine manufacturing.

Minihydro plants cannot be mass produced. Each one must be individually designed.

Three kinds of self construction of turbines can be distinguished:

a) complete local manufacturing of a design requiring no specialised production processes
b) partial production of turbine components with sophisticated parts imported (eg partial import of pelton buckets, nozzle and governor)
c) local manufacture of foreign design under licence with appropriate technical support from outside

This paper is mainly dealing with type a) of local turbine manufacturing. It might be difficult to get a suitable design for a proposed layout.

Even if a design is available, manufacturing must be supervised by somebody who has the knowledge of that particular design and experience in its fabrication.

While doing local manufacturing of water turbines, experience and know how will be gained gradually. To avoid overrating of one's own capacities, at the beginning very small turbine units, not larger than 50 kW power output should be envisaged.

The design must be as simple as possible. If a design is not suitable for the existing manufacturing facilities it can be altered by experienced manpower to suit local demands.

Emphasis must be laid on the use of material from local resources in order to create links between local industries and to be independant from imports. The variety of material and profiles used should be as small as possible to cut down the weight, the manufacturing cost and time.

Besides administrative staffs technical personnel for civil work, fabrication and installation are needed to run a turbine business. For fabrication, besides trained workshop mechanics, additional information and supervision by somebody who has the knowledge of that particular design and experience in manufacturing is needed.
Installation teams, whether they are mechanical, electrical or civil, must have good knowledge and experience. They must also be equiped with sufficient, suitable and good tools. This will be helpful for them to overcome difficulties in some situations.

5. The Crossflow Turbine T3 (*)

5.1. The Development of the Turbine

Historically, all improvements on traditional water wheels resulted in the development of water turbines. Most recent efforts in Nepal in this respect resulted in the construction of a Segner turbine (x) for power output upto 10 kW.
Already some years before various designs of propellor and crossflow turbines have been developed, tested, evaluated and installed in Nepal. They were mainly used for mechanical power applications.
Over 100 small turbine installations with locally made machines are in use nowadays. This became possible with the experience gained in preceeding activities. Also a few small electricity generation units were installed.
In 1981 a new design of a crossflow turbine T3 was introduced. Since then over 30 installations have been completed. The design is based on the experience of former designs, suits the manufacturing possibilities of small workshops, uses commonly available materials and has been tested in Switzerland.
For simple mechanical power applications the turbine is handregulated, but also a mechanical governor can be attached or an electronic load controller can be used in combination with hand regulation.

5.2. Selection of the Turbine Width

To serve the necessary specifications the turbine width bo is variable. All other dimensions remain the same (see appendix I).
In the following, an example will be calculated to find the width bo of the turbine.

(*) design and layout manual will be available at SKAT
(x) brochure available at SKAT in April 1983

For a given grosshead Hg of 30 m the turbine should produce a power output P of 30 kW.
How big is the necessary water quantity Q and the turbine width bo?
To determine the working head Hn (net head), all losses ΔH must be deducted from the gross head Hg.
Net head Hn = Gross head Hg - Losses ΔH
To determine the losses, the water discharge Q must be known. To get the approximate discharge to generate 30 kW, a net head of 27 m and an efficieny of 0.7 are assumed.
The discharge Q is calculated according the following formula:

$$Q = \frac{P \times 102}{Hn \times \eta} = \frac{30 \times 102}{27 \times 0.7} = 162 \text{ lt/s} \quad Q \text{ (lt/s)} \quad P \text{ (kW)} \quad Hn \text{ (m)}$$

With the approximate discharge Q the head losses ΔH can be calculated. ΔH is the sum of all losses, eg. entry and exit losses, pipe losses and suction head losses.
With entry and exit losses of 0.4 m, a penstock length of 50 m and a diameter of 250 mm the pipe losses are 2 m for 162 lt/s, the suction head losses are calculated as o.6 m.
The total losses are ΔH = o.4 + 2 + 0.6 = 3 m
Afterwerds the supposed net head is recalculated and the discharge is rechecked, or the penstock diameter must be altered to get the required output.

$$Hn = 30 - 3 = 27 \text{ m}$$

The efficiency of this turbine is best at a butterfly valve opening β of 87.5 %. In graph no. 1 we find that the efficiency at 27 m head and 87.5 % opening β is about 0.71.
To determine the turbine width bo, which is variable in the design, the specific discharge Qs for a butterfly valve opening of 87.5 % must be known.
On graph no. 2 Qs for a β of 87.5 % can be found as 0.145.
With the formula $Q = Qs \times bo \times \sqrt{Hn}$ the turbine width bo is calculated:

$$bo = \frac{Q}{Qs \times \sqrt{Hn}} = \frac{162}{o.145 \times \sqrt{27}} = 215 \text{ mm}$$

The next standard size for the turbine width bo 220 mm is chosen. The actual Qs is now

$$Qs = \frac{162}{220 \times \sqrt{27}} = o.142$$

The opening β for this Qs is found 83 % on gragh no.2 and the corresponding efficiency is 0.7 (graph no. 1). So the initially supposed efficiency proved to be correct. Otherwise the calculations would have to be revised.

The number of revolutions per minute n (RPM) for a net head Hn of 27 m is found on graph no 3 as n = 1010 RPM, which is the optimal speed for best efficiency. If the design speed is different from optimal speed, the efficiency must be corrected according to other graphs. Also the discharge will change.
Part load efficiencies can be found in graph no. 1.

Now that the turbine width is determined according to an example, let us have a look at the actual turbine manufacturing.

5.3. Fabrication of T3 Crossflow Turbine

The T3 crossflow turbine can be manufactured in any small mechanical workshop, which has the following basic equipment plus technical assistance or necessary experience.
Workshop equipment:

- cutting devices; saw, gas and shearing
- arc welding machine
- drilling machine
- milling machine
- lathe machine (height above bed 125 mm)
- basic tools like drill, taps, files, hammer, spanners, screw drivers and so on

The fabrication procedure is described below in headwords. The tubine consists of different sub assemblies. As an example for the fabrication of a sub assembly the manufacturing of the turbine rotor is described in detail.

- first prepare the material for all the turbine parts according to the material lists
- the material for the rotor assembly is listed on appendix IX
- the required number of intermediate discs is subject to permissable stresses in the blades

and must be determined according to the head and the turbine width (*)

- cut the rotor shaft to the correct length
- make the keyways now in the shaft. It is easier to make them before completing the rotor.
- cut a sheet of 2.5 mm thickness to the correct length of bo + 30 mm (appendix V)
- cut 32 strips of 49.5 mm width
- heat the blades up to a temperature of 800 °C
- roll or press to the correct shape
- check and correct twist if necessary
- do heat treatment to release the stress
- file the edges of the blades, which will be pointing to the centre of the rotor carefully according to appendix XIV
- cut the required number of discs out of a 4 mm plate
- mark the centre holes (appendix VI)
- bore the centre hole diameter of 50.5 mm
- machine the outside diameter of 205 mm

There are different ways to make the slots into the discs. One way is the following (appendix VI):

- glue a paper jig to the discs and make sure the centres are matching
- punch the centres of the holes for the slots
- drill holes of 3 mm diameter
- make slots with a slitting saw machine
- finish the slots by filing

This procedure of making the rotor discs is made with all discs together at a time. If a plasma cutting machine is available, the slots can by cut nicely in one step. To cut them by gas cutting is not possible, because the parts between the slots will be overheated and bent. Also nibbling is not possible, because of the small width of the slot in comparison to the thickness of the discs.

Once the rotor shaft, blades and discs are prepared continue as follows (appendix VII):

(*) information is contained in the T3 design manual

- place the discs on the shaft
- fix them by tack welding
- check for correct position and right angle
- put 3 to 4 blades into the slots
- make sure that the slots are aligned in one row and that the blades are at right angle to the face of the discs
- fix these blades by tack welding
- fit the other blades and fix them by tack welding
- check again for right angle
- do full welding alternatively on opposite sides of the discs to avoid twisting of the rotor
- the end discs must be welded to the blades only on the outer face of the disc, which is very important not to decrease strength of the blades
- it is sufficient to weld the intermediate discs from one side only
- weld the discs to the rotor shaft

Afterwards the rotor is finished on the lathe machine (appendix VIII).

- turn the shaft to a diameter of 50 mm and the rotor to a diameter of 200 mm, file the outer edge profil of blades
- face the blades, be careful not to cut away the welding seam

After manufacturing the base frame and the 2 u-shaped flanges of the housing, they are fixed together by tack welding. The holes in the base frame and the flanges are drilled at a time, to make sure that they are fitting (appendix XVI). Then the housing is finished and mounted to the rotor (appendix XVII & XVIII).

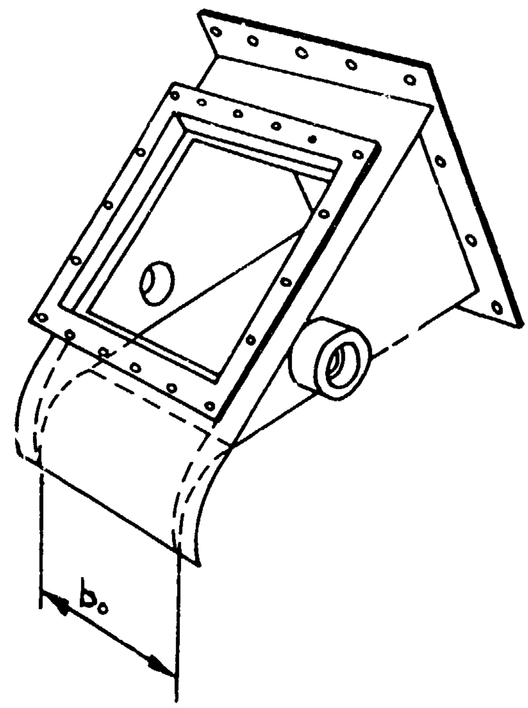
After fabrication of the inlet (appendix XIX & XX), the top and bottom plates must be made flush with the radius of 100 mm (appendix XV). Before welding the inlet to the housing (appendix XXI), put a sheet of 0.3 mm thickness around the rotor, to maintain a minimal gap between the inlet and the housing. This is very important to keep the water losses small and the efficiency high (appendix XXII). When fixing the butterfly valve to the inlet (appendix XXIII), it is very important to have no gap between the top and bottom plates

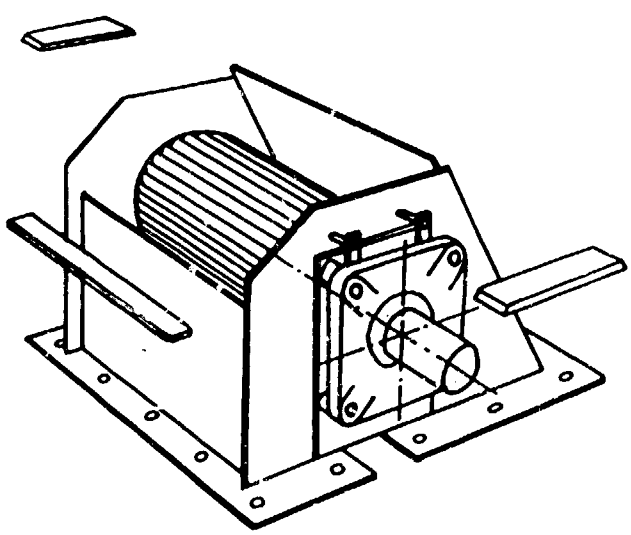
of the inlet and the butterfly valve.
Now, when the turbine is complete (appendix XXIV), one has noticed, that there are many things to pay attention to when locally manufacturing turbines.
There is a vast field for further considerations and development. For instance the decreasing efficiency with increasing head is most probably due to a too big water discharge for this size of the housing.
However this turbine has proven to be a good, simple and reliable machine, if carefully manufactured.

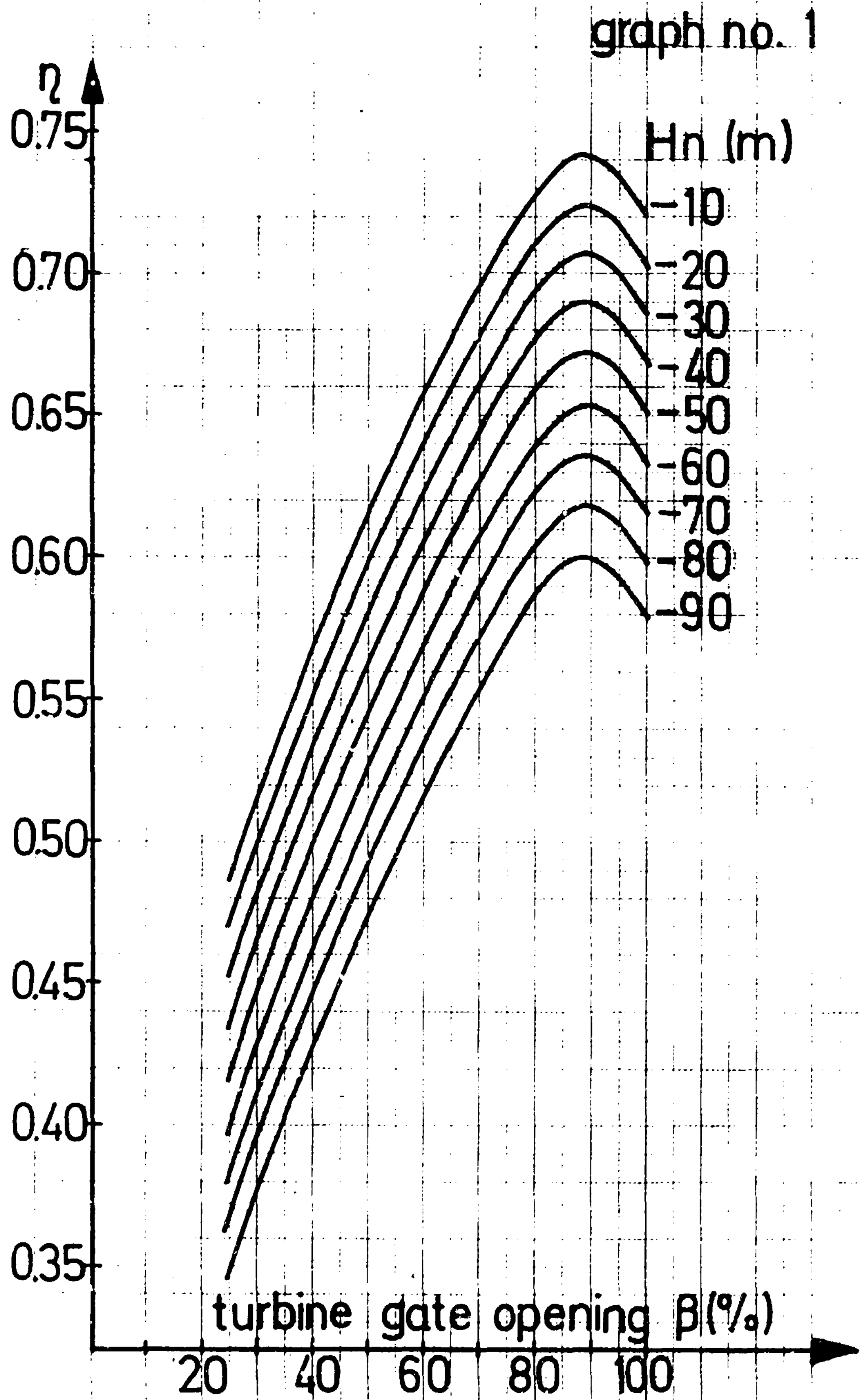
6. Conclusions

Water power is nothing new to industrialised countries. Today discarded penstock pipes and turbines can be seen standing at the backyard of houses. But the know how to build such simple and reliable machines has been lost. It must be learned again how to build small hydro plants in a way that they can run economically. Foreign manufacturers are in possession of mini hydro turbine designs. But they are costly, sophisticated and complicated to manufacture.
On top of that, foreign manufacturers are reluctant to provide their designs and knowhow, because they are anxious to keep their standard of production, because they would be responsible for the specifications, because of their investment cost in the design, development and testing of their equipment and because of their profit.
However some of the reputed manufacturers are ready for different kinds of collaboration. But their services and information have to be paid for at considerable fees.
Nevertheless it has been proven, that local turbine manufacturing is possible. One of the biggest problems is to get suitable designs, technical assistance and practicable technology transfer.
SKAT, among a few other institutions is disseminating information on existing experience in this field. As interest in small hydro- power grows, there is a need for increased activities and for this, relevant organisations have to be strengthend.

<u>Variable Turbine Width bo</u>

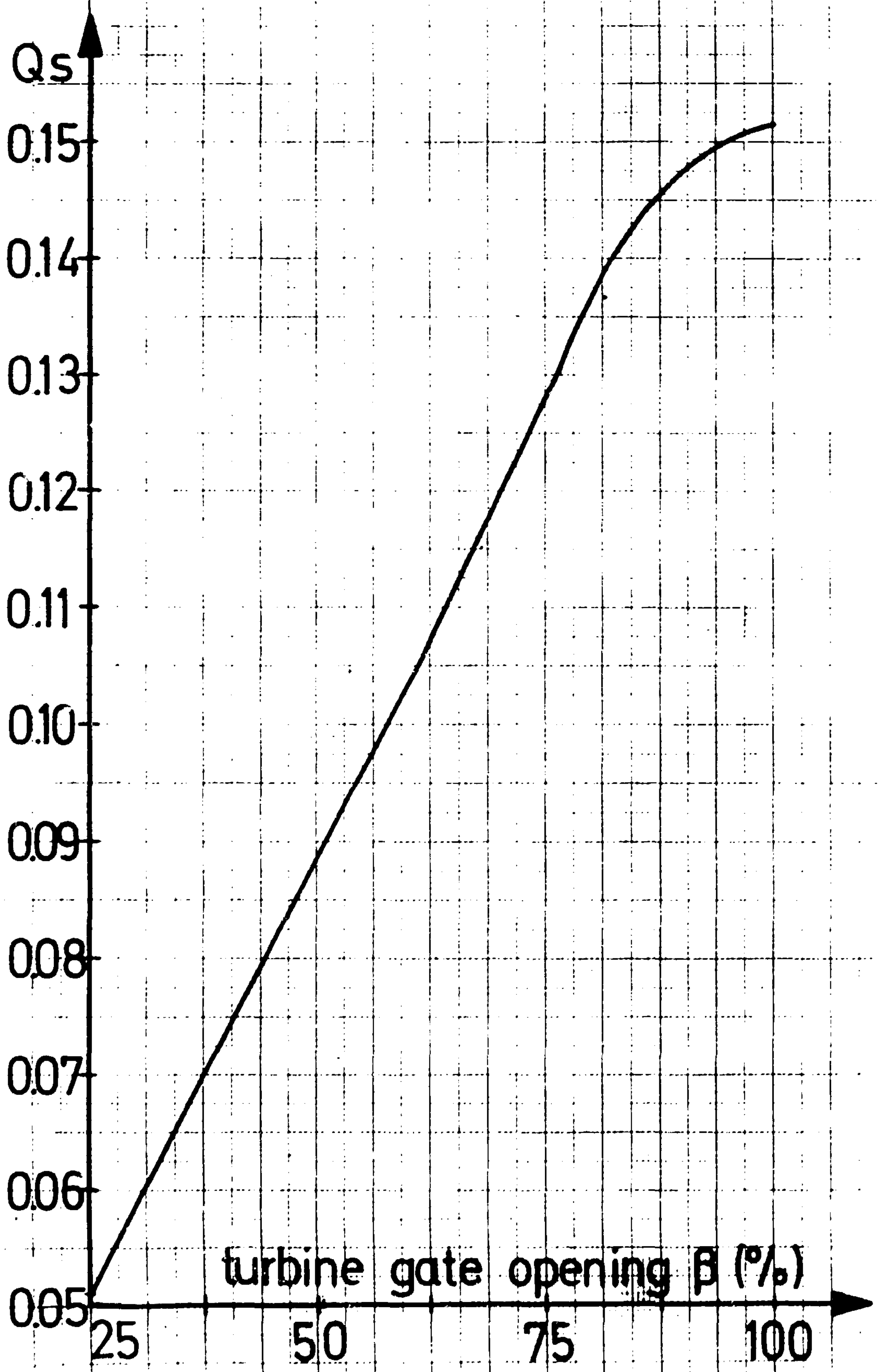





graph no. 1
η
0.75
0.70
0.65
0.60
0.55
0.50
0.45
0.40
0.35
Hn (m)
10
20
30
40
50
60
70
80
90
turbine gate opening β (%)
20
40
60
80
100

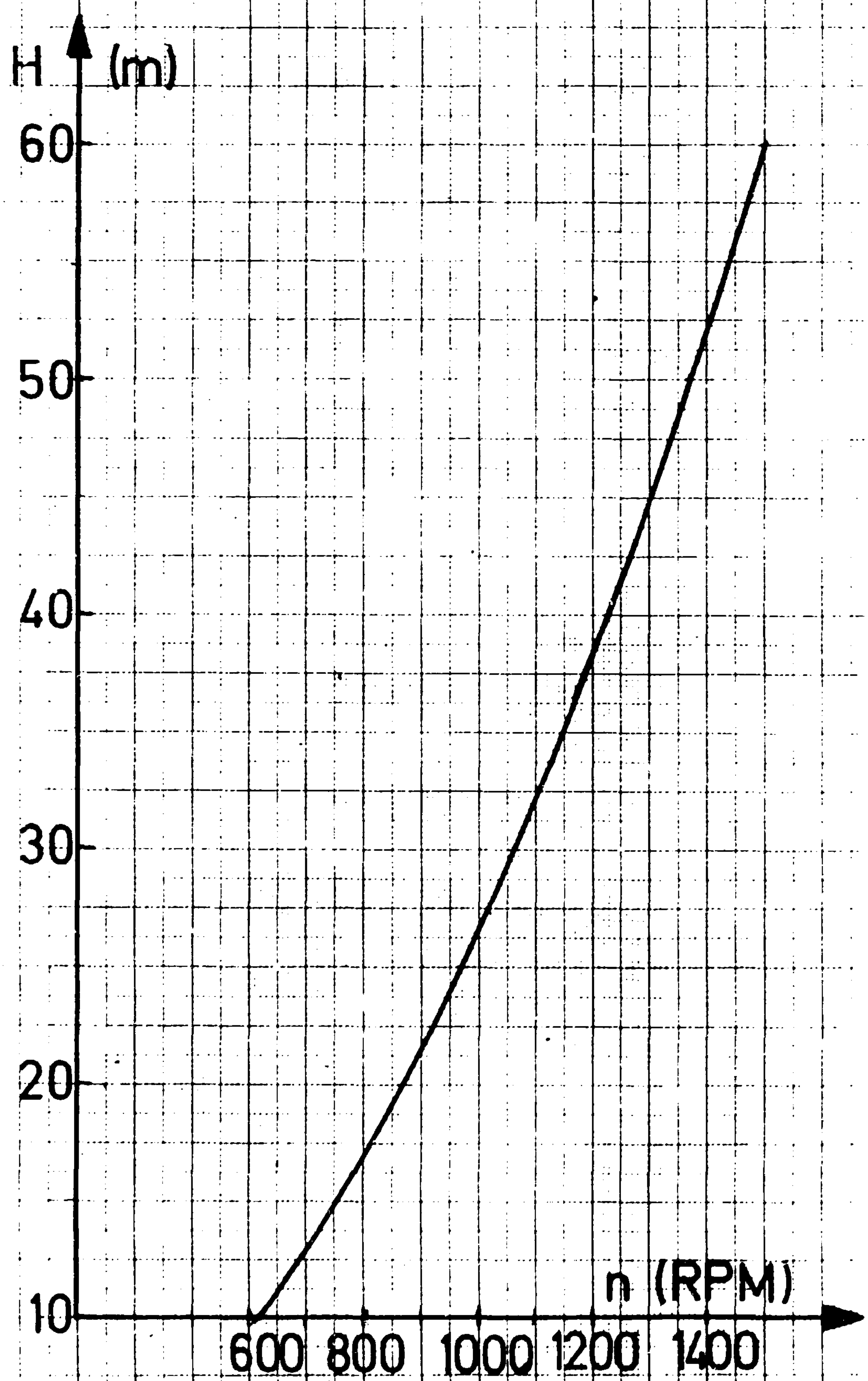
26 2.83

graph no. 2

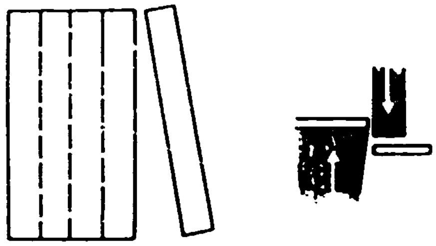
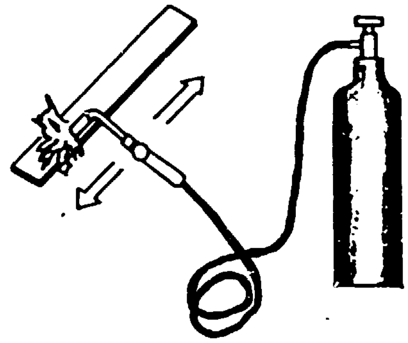
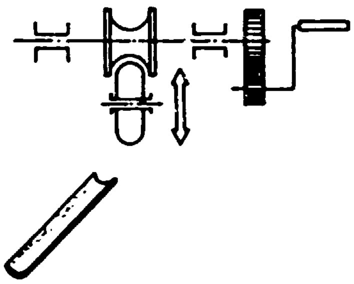
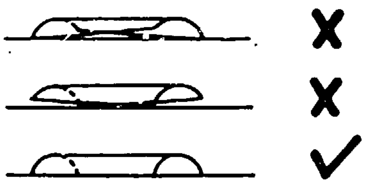
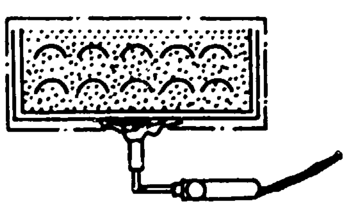
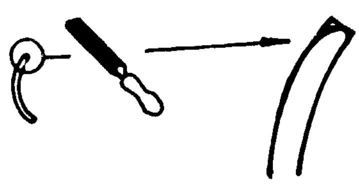


26.2.83

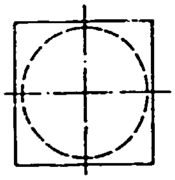
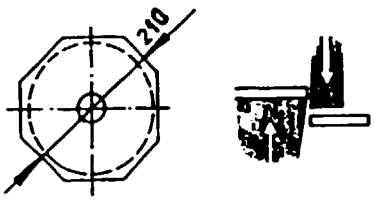
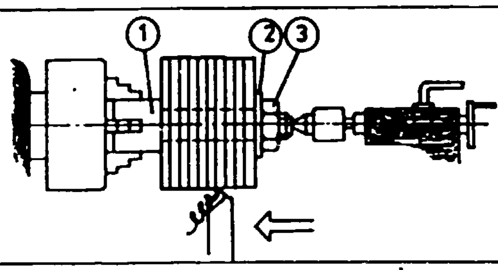
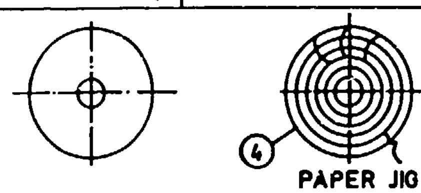
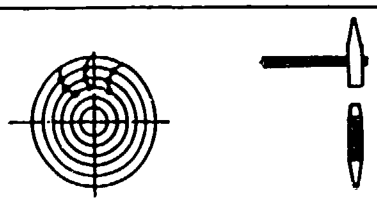
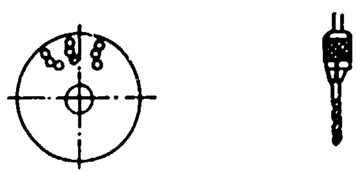
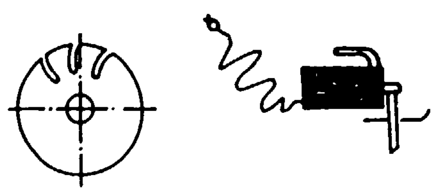
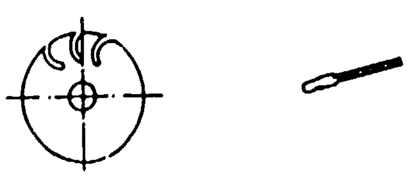
graph no. 3



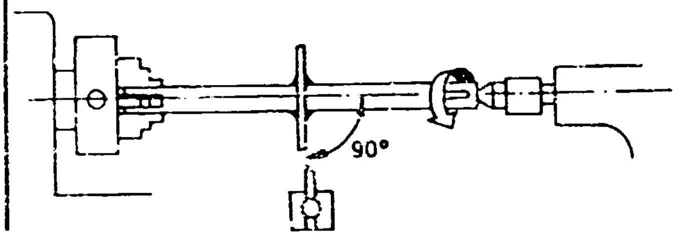
26.2.83 PE

	Take 2.5mm M.S.Sheet and shear it off according to required size.
 800 °C	Heat the sheet up to 800 ^{o}C.
	Roll it carefully.
	Check wkether the blade is twisted. If so correct it.
 600 °C	Pack the blades singly,as shown, in a metal box with cast iron chip stuffed all around them.Heat the box uniformly from all sides up to 600 ^{o}c. Let it cool in air by itself.
	Make the edge profile by filing according to the drawing. Let the other end of the blade be as it is.

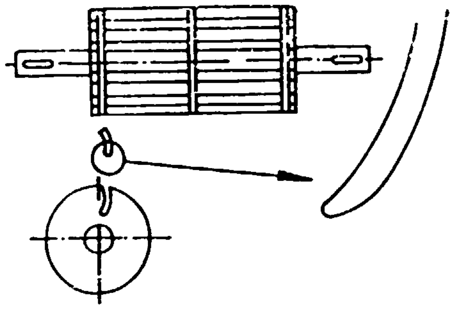
ROTOR DISC FABRICATION.

	Prepare mild steel sheet according to measurements (4mm thick by 210 x 210). Mark centre and draw a circle of ø 205.
	Cut the four edges off by shearing. Bore a hole of ø 50.5 in the centre.
	Use disc holder to put together 10pcs. Mount it on Lathe as shown and turn to ø 205.
	Apply quick drying glue throughly on back side of the paper jig.Stick it on the disc.Make sure the paper jig coincides with disc.Press all over and let it dry.
	Centre punching.
	Drilling (ø 3).
	If necessary do soft annealing at Temprature of 600 °C. Make slots with sliting saw machine.
	Finish by filing.Atleast 2pcs at a time.

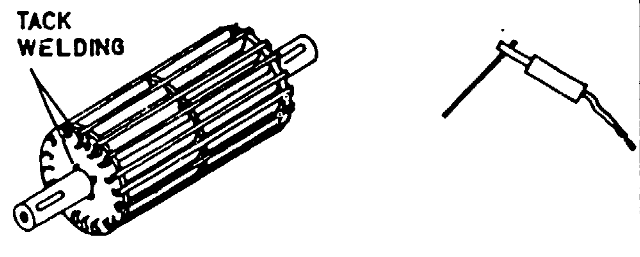
ROTOR FABRICATION.1



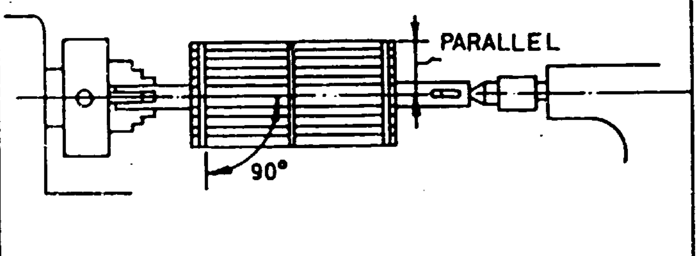
Place the middle disc in position. Do tack welding from both sides. Check the axis of the disc should be 90° to the axis of the shaft. Make full welding.



Place the outer discs in position. Insert the blades in the slots. Make sufe that the filed dege profile falls inside. (See drawing)



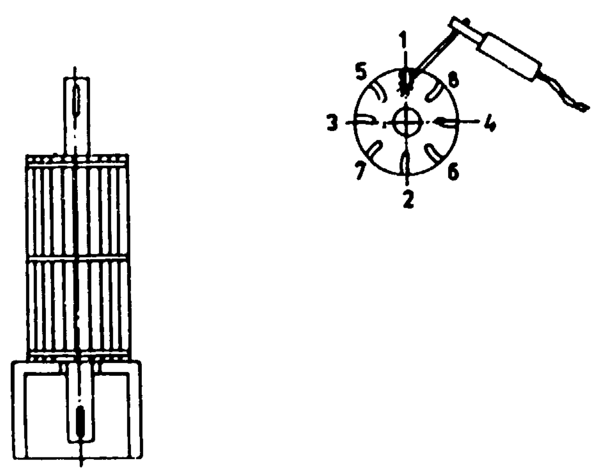
Do tack welding of the blades on the outer disc and outer disc on the rotor (as shown) from out side only.



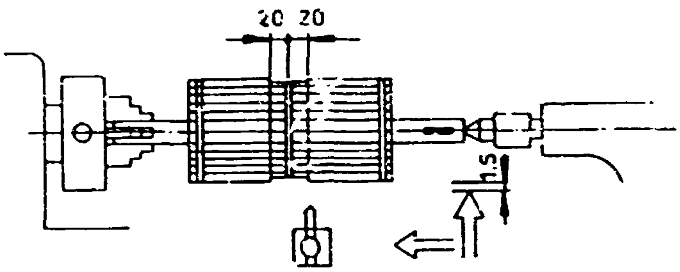
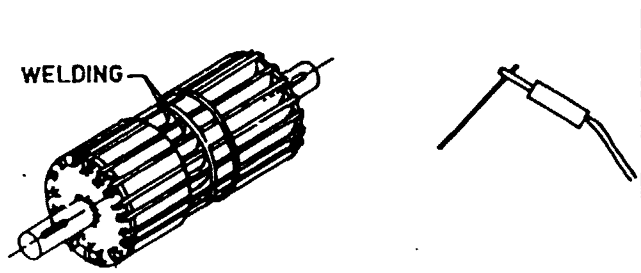
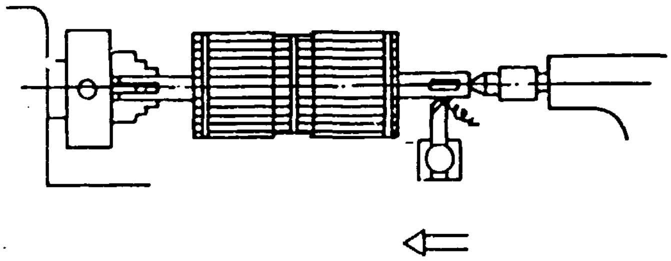
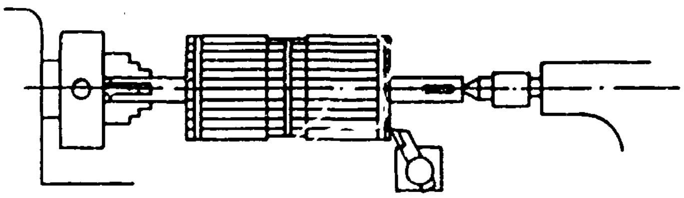
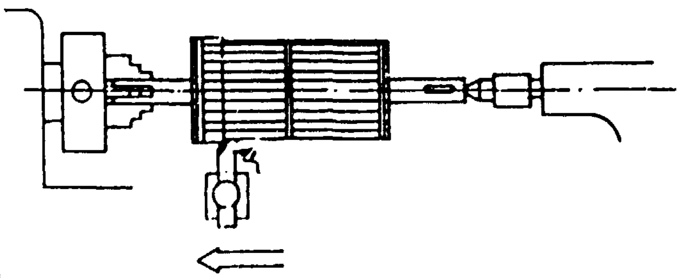
Mount it on Lathe and check ;

a) Disc should be 90° to the axis of the rotor.

b) The blade should be parallel to the axis of the rotor.



If it is alright place the rotor vertically up (as shown) on a drum or a specially made table with a hole big enough to put the shaft end thruogh. Continue welding from out side. only and alternately (as shown)

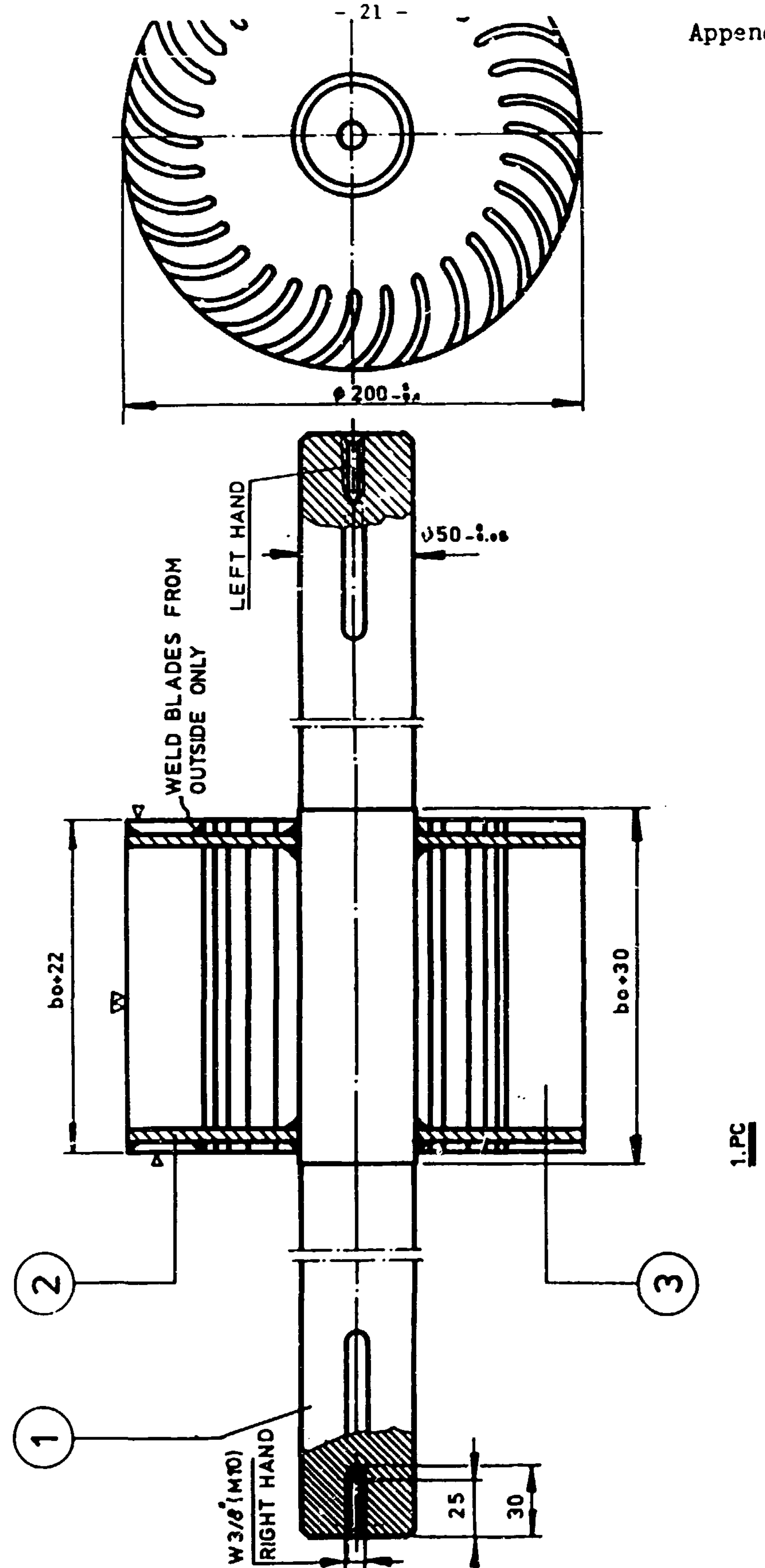
	Turn eachside up to 20 mm from the middle disc to Ø 202. Remove burr which may obstruct welding rod.
	Make full welding on the middle disc alternatively opposite side of the disc.
	Turn the rotor shaft to Ø 50
	Facing off
	Turn the rotor to final Ø of 200. Turn the rotor 180^0 to carry on turning and facing of the other side. Remove burr from rotor blade

Appendix IX

POS	PCS	DENOMINATION	DRAWING NUMBER	SPECIFICATION
1	1	ROTOR SHAFT	T3/08/01	M.S.ROD φ 2" (50,8) X bo-570
2		ROTOR DISC	T3/08/ 02	M.S.SHEET 4MM X 205X205
3	32	BLADE	T3/08/ 03	M.S.SHEET 2,5MM X 49Xbo+30

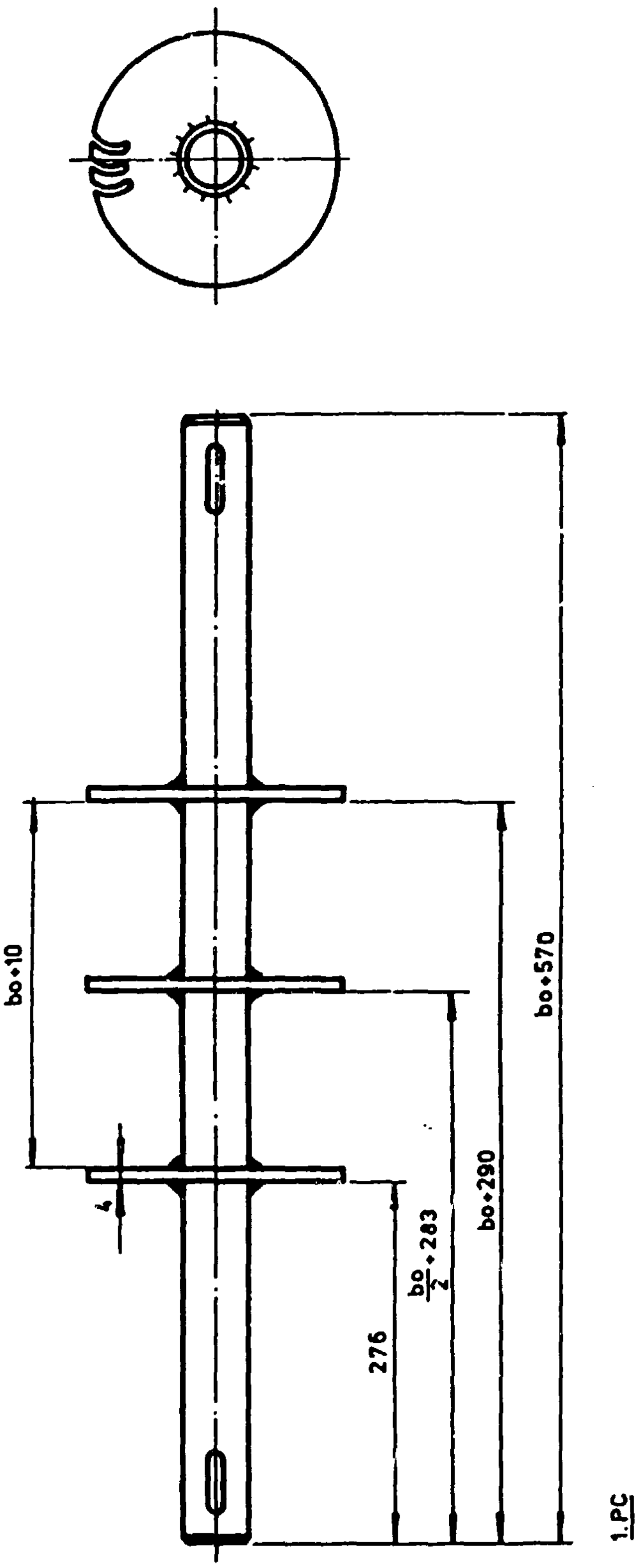
ROTOR ASSEMBLY T3/08/00 | S27

Appendix X



ROTOR ASSEMBLY T3/08/00 | S28

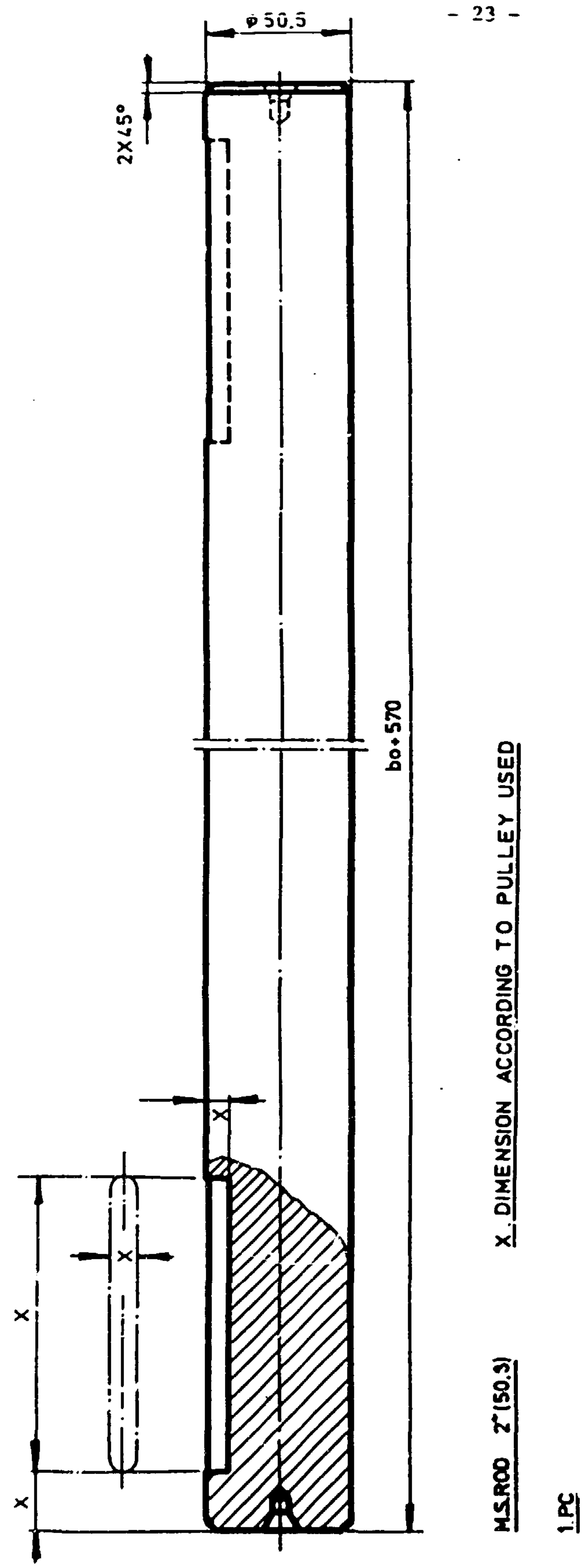
1:2,5



ROTOR DISC ARRANGEMENT 'B'

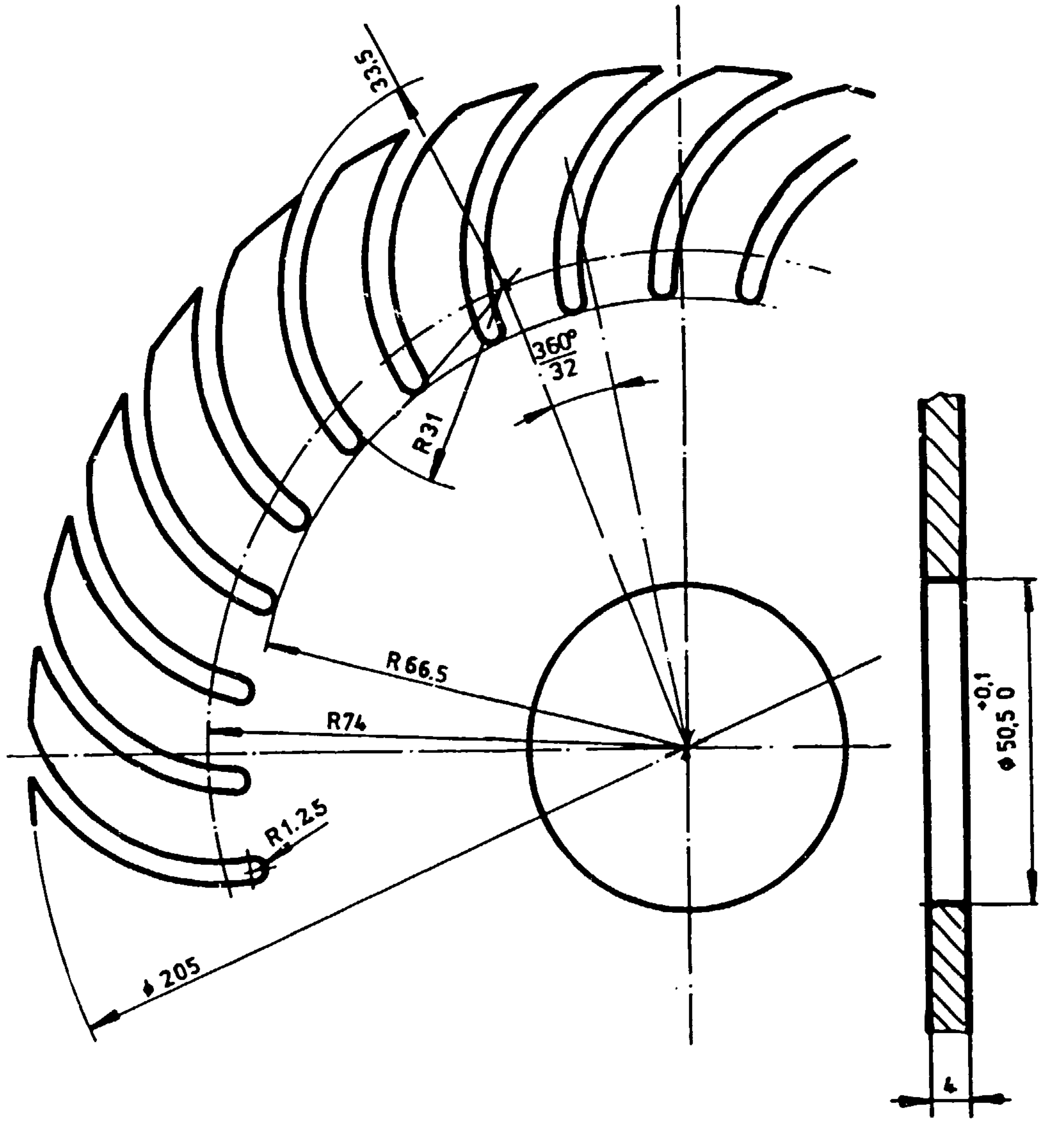
1:5

T3/08/00 | S30



ROTOR SHAFT (PREMACHINED) T3/08/01 S34

1:2



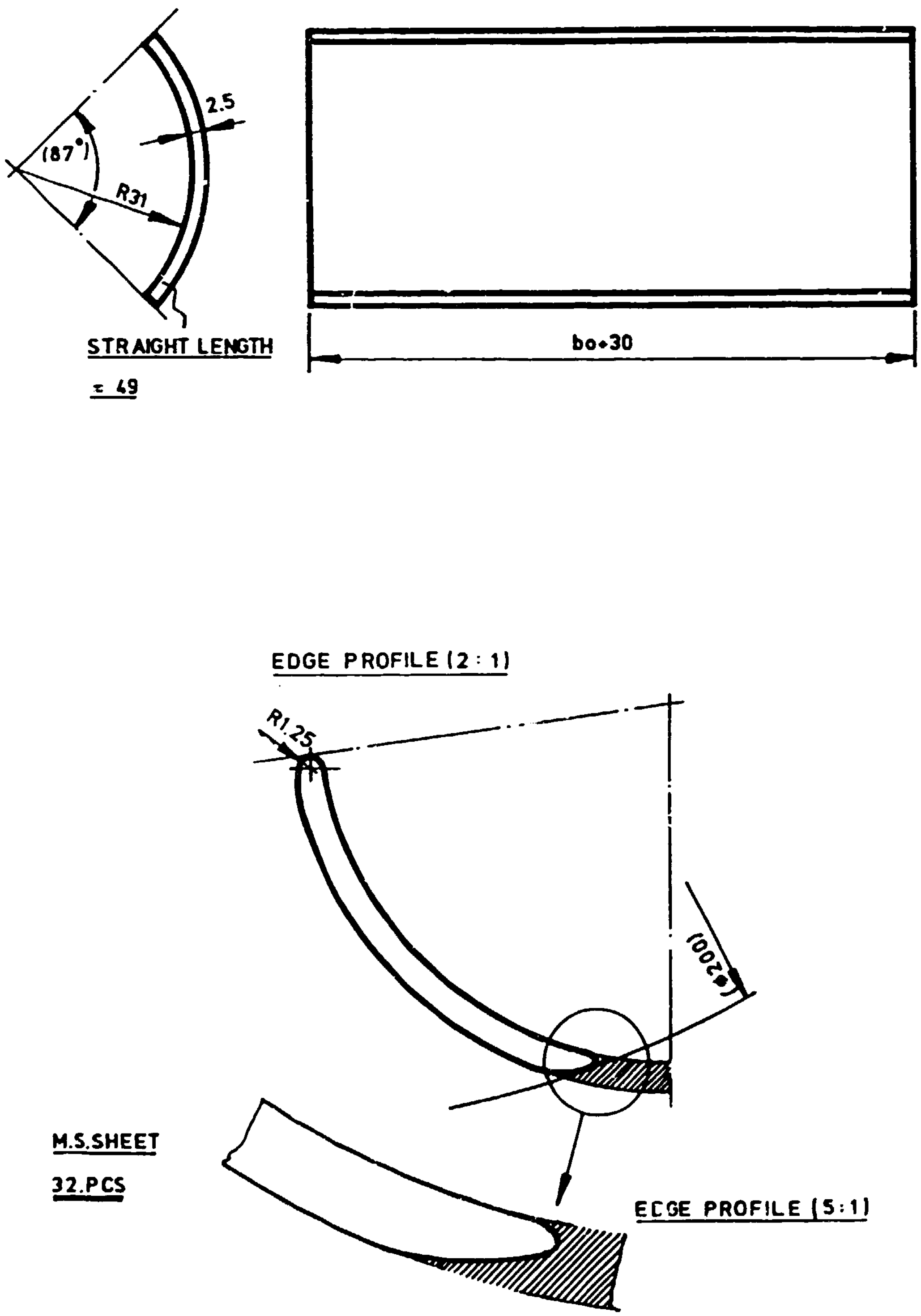
M.S.PLATE

PC

ROTOR DISC

1:1

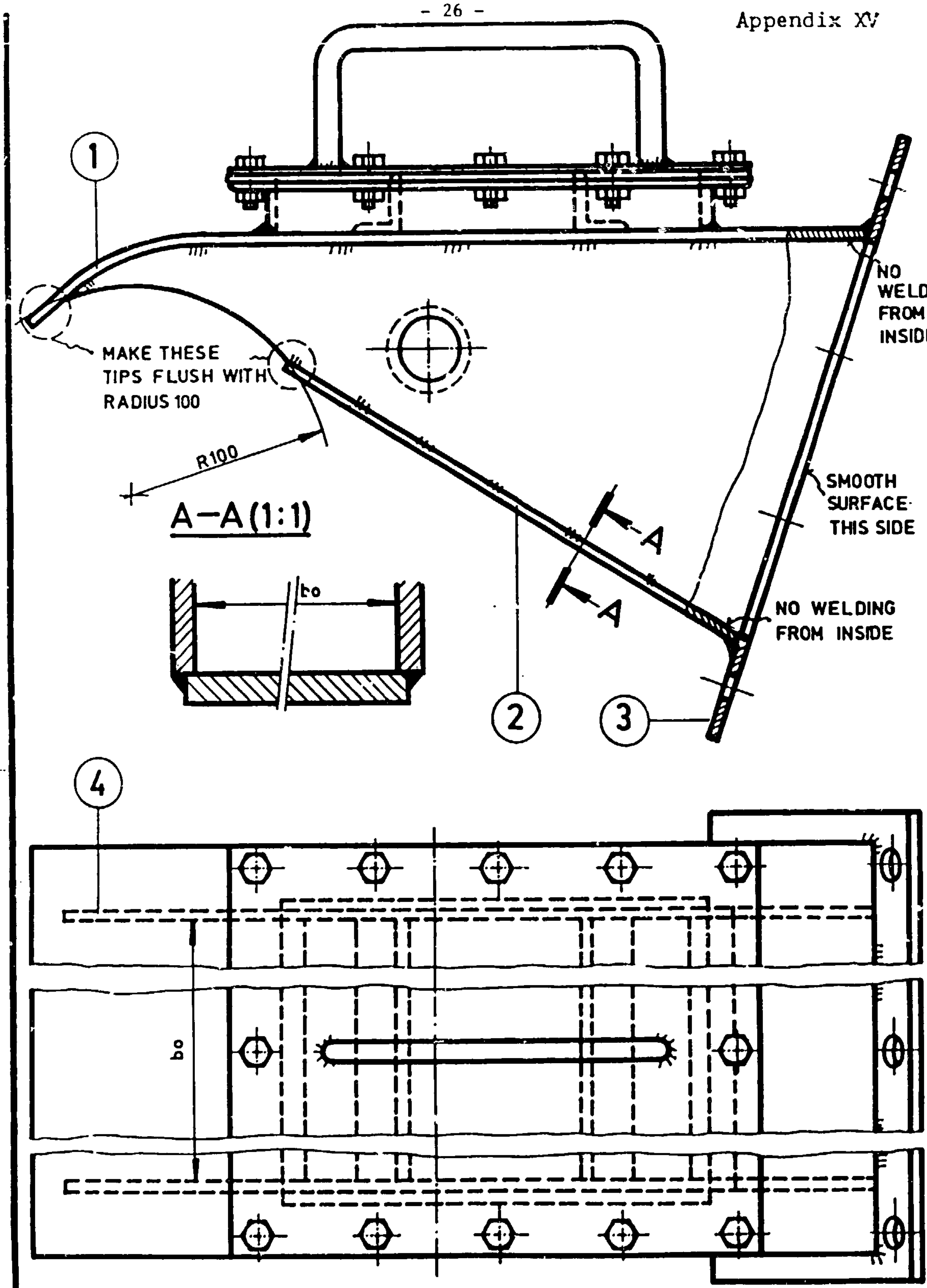
T3/08/02 | S35



BLADE

1:1 (2:1) (5:1)

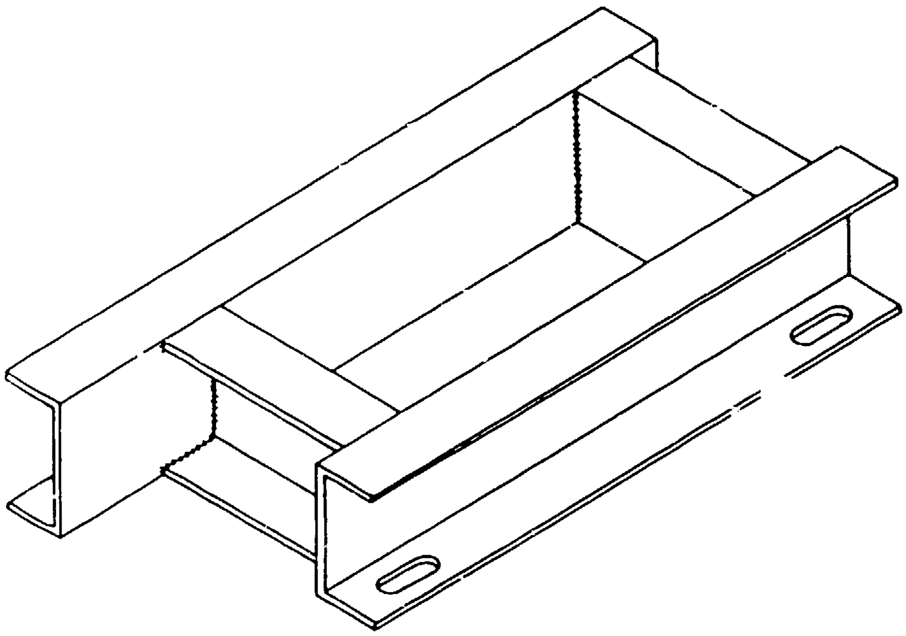
T8/08/03 | S36

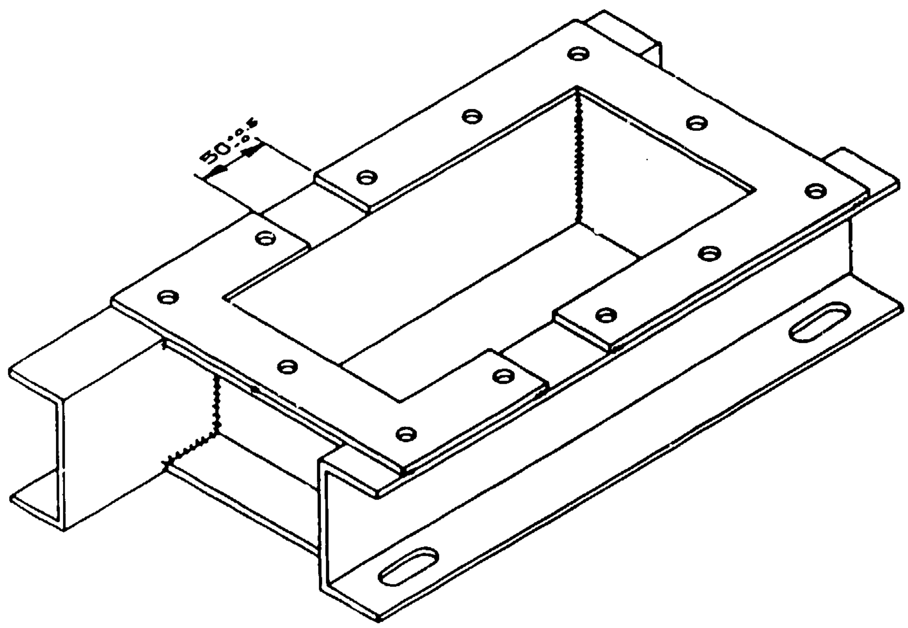


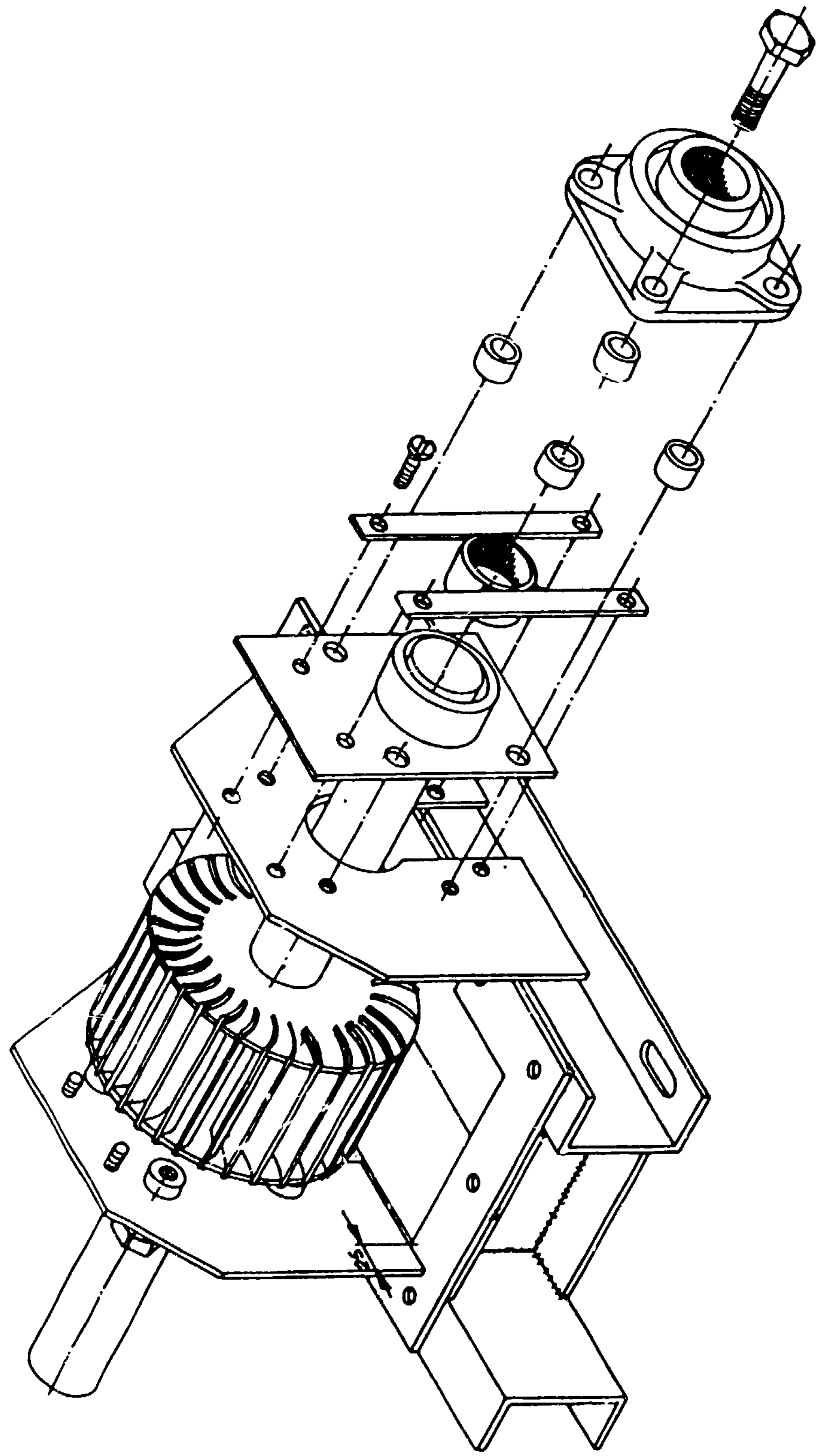
INLET ASSEMBLY

1:25 (1:1)

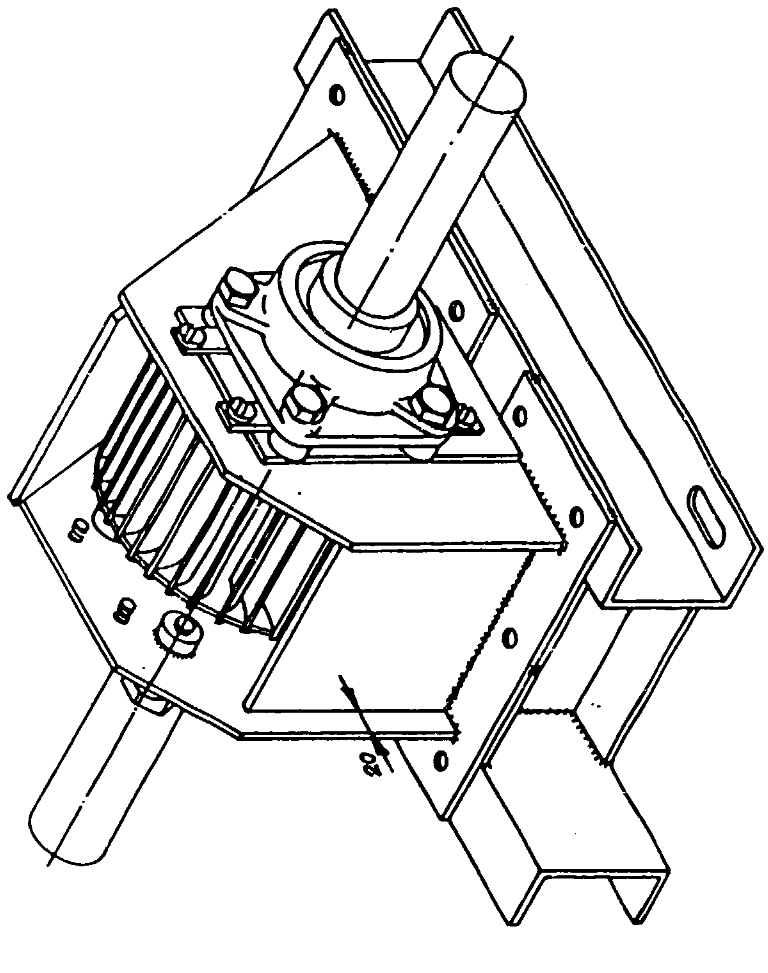
T3/06/00 | S16

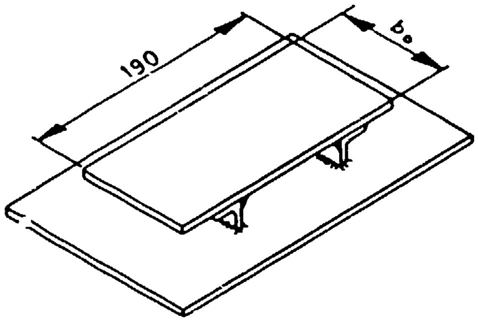


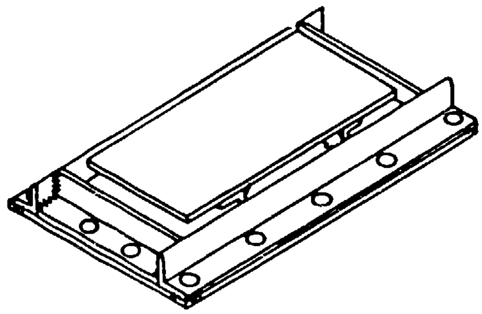

50 +0.5 -0

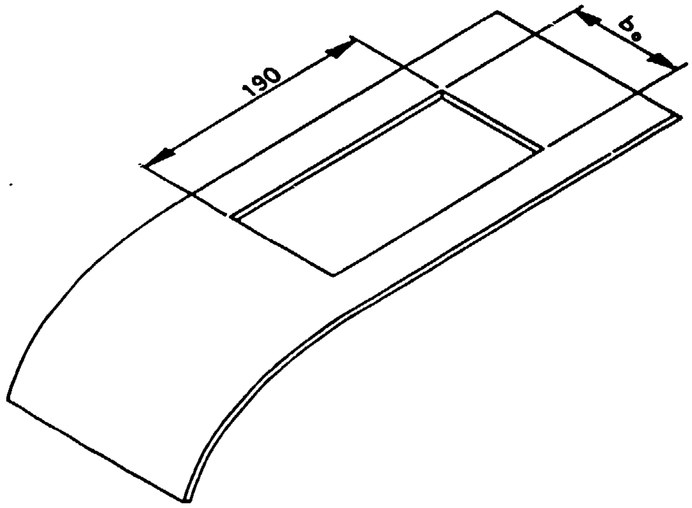


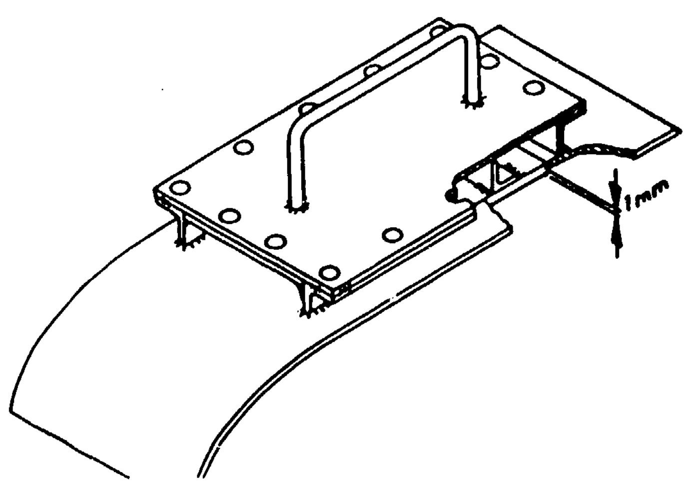
Appendix XVIII

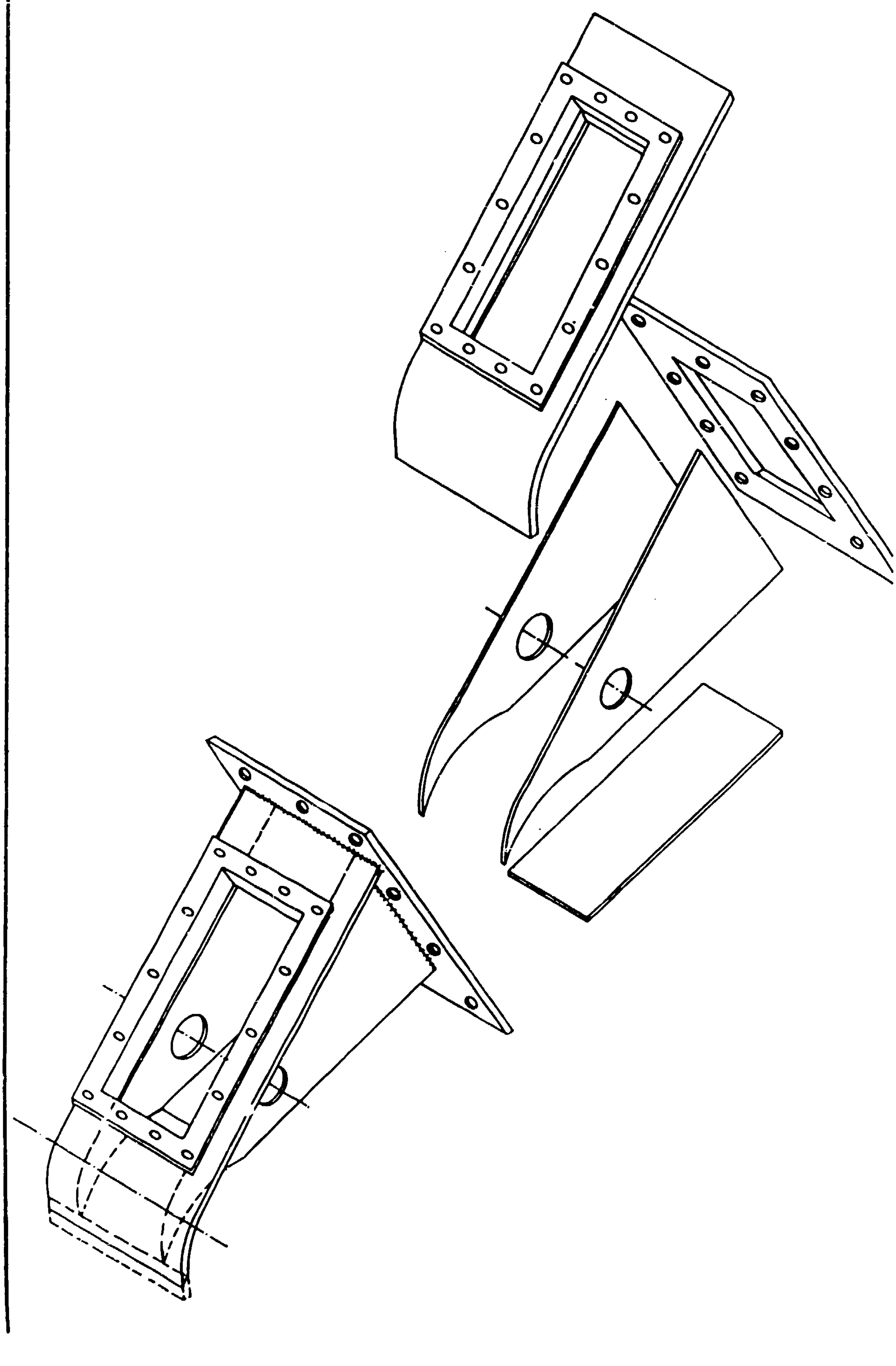


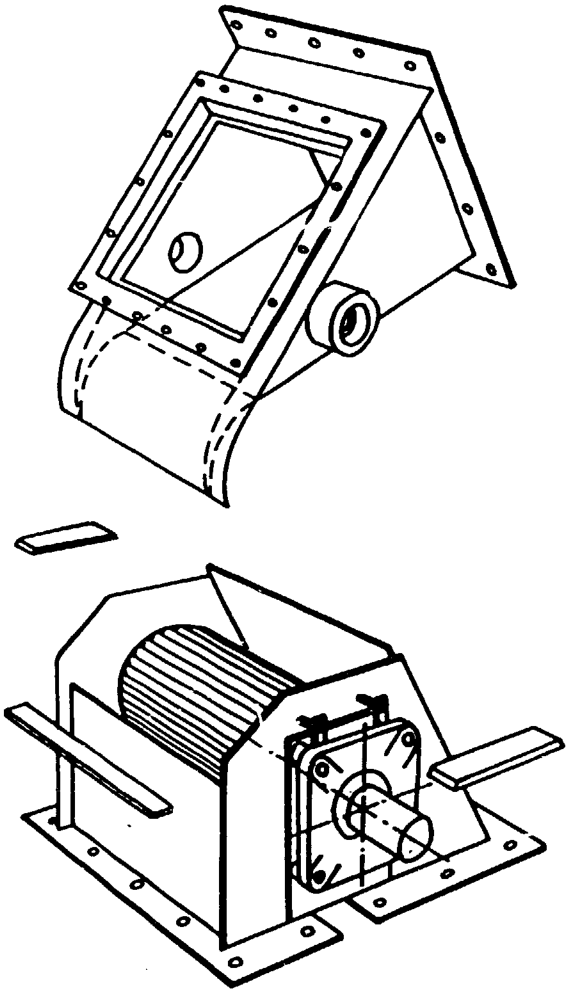

190
bo

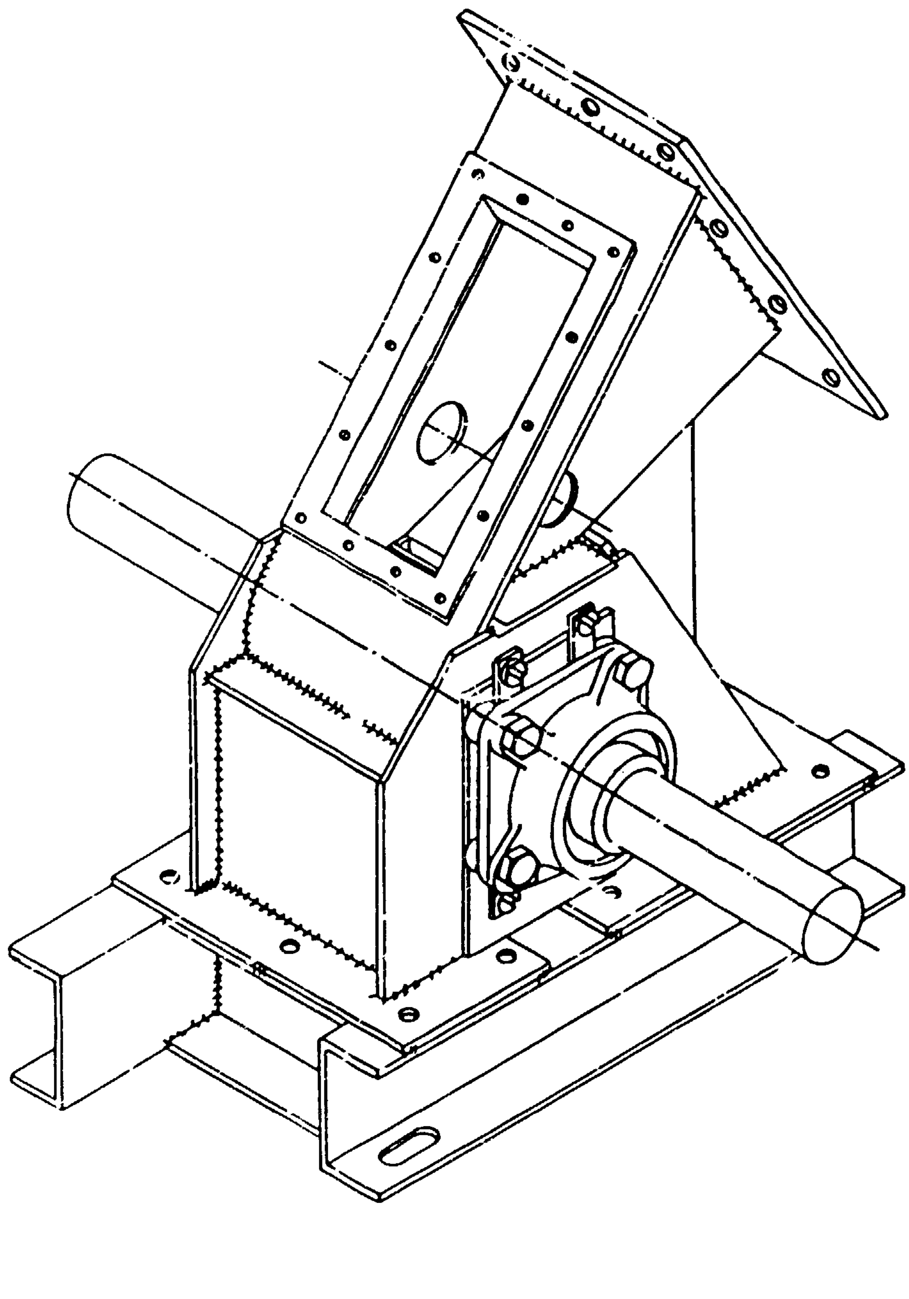



190
bo


1mm







Appendix XXIII