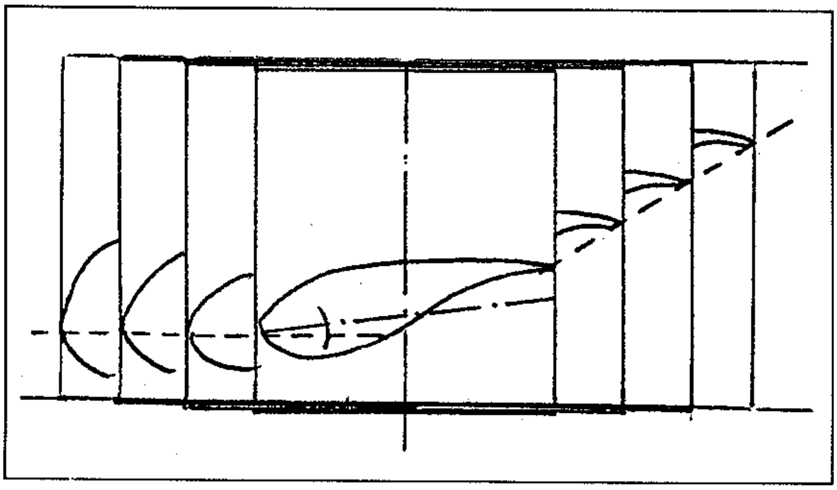
SYSTEM FOR MANUFACTURING WOODEN ROTOR BLADES FOR SMALL WIND MILLS



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REPORT

SYSTEM FOR MANUFACTURING WOODEN ROTOR BLADES

FOR SMALL WINDMILLS

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Folkecenter for Vedvarende Energi, May 1991

Short description of the principles

With the need for small series of wings with different airfoil patterns and aerodynamic characteristics, we decided to build a hand-controlled copy-millingmachine in a simple manner to keep costs low both in building it simple and though reliable and shorten machining time for one wing down to 1-2 houres.
Generally, the problem of small wooden wings is their price, making machines up to 10 kW quite expensive. To run a small production, also in third-world-countries, it is nice to have a machine working one-man-operated , with standart-parts and easy to understand, following the princip of copy-milling.
Here a sensor-roll transmits the airfoil-pattern via parallelogram to a tool, carving out the airfoil out of a wooden beam. The tool is a set of two or more standard sawblades driven by an electric motor. The airfoil-patterns lie as a hardfoam-model of each the up- and downwindside parallely besides a tapered, laminated wooden beam on a machine-table. There are also rails mounted on this table, leading a wagon with all equipment, such as roll, tool, motors, parallelogram, feeding-motor, sawdust-blower and control-unit in parallel to model and beam.
So it is possible, to cut out each cross-section of the wing, and, seen in the continuity of the long-axis of the wing, manufacture a rotor blade reproduceable in any number. The fine surfacework follows this step,before this you have to build the models and prepare a wooden beam.
So we have three main chapters, making out the whole production-circle:

1. The models. The shape, material and production
2. The laminated beam. Preparing wood and lamination.
3. The machine. How to build, data, necessarities in design, how to operate and maintain.

This report describes the manufacturing-system and the copy-machine in it´s recent prototype stadium of May 1991, after a five-months-stay at the Folkecenter.
I was inspired and supported by Lars Yde, Folkecenter, and I hope there will be more work on this system in future.
All data is special for manufacturing wings applied in the FC 4000, a twobladed windmotor with direct-driven Permanent-

magnet generator and a 4m-diameter rotor made out of laminated wood , output power 1,5 kW at 10 m/s windspeed.
Generally, it is possible to build blades with a length of up to 4,3 m and a chordlength of max. 300 mm,thickness max. 200 mm.

Chapter 1
The models

When using this machine for the production of rotor blades, you need the profile data for the airfoil, calculated for each purpose and output power. A simple and cheap method to make these models is to cut them out of hard foam, 80mm thick, normally applied for floor-insulation, with a hot wire which is melting away a few material. It is possible to cut out nearly every straight form you want.Seen closely, an airfoil(when designed for this), consists of several tapered sections with a special chord for each section. The number of sections can vary but the less, the more simple can the model be. In one way the rotor design should consider the possibilities and the efficiency of model-building. The most simple wing would have the same chord in the tip and in the root, being rectangular, untwisted and totally equal. This means losing a lot of power-factor and is not necessary, because this manufacturing system can also do more complicated wings, being quite flexible.
Because of the FC 4000 wings we need for several tests are tapered but untwisted, with the same setting angle along the entire rotor-axis and made as twobladed rotors out of one piece, saving joints and dynamic loaded composite elements, we decided to choose four cross-sections with chord lengthes between 100 and 250 mm. The profile choosen was Wortmann FX- 163-series. The setting angle was choosen to be 7°.
When Ileft the Folkecenter, there were also some thoughts about using the new NASA LS-1- profile for the FC-4000. This Profile has got some advantages more, making it more suitable also for the FC-4000 and this manufacturing system. It has, for example, adefined thickness at the trailing edge, a good thing when you work in wood.

The method of cutting out the three sections of the model, each 667mm long,required for 2000 mm rotor radius, is like this: first cut out tapered pieces out of the 80 mm-foam, width of each end is calculated this way:

$$b = \cos \beta \cdot c + 5 \text{ mm (mm)}$$

β ≙setting angle , c ≙chord length , b ≙ width of model

The foam can simply being cut with a bigger circular saw or bandsaw. After this procedure you´ve got three pieces of foam, tapered and measuring roughly 100 to 150, 150 to 200, 200 to 250 mm width. Each one is 667mm long and 80 mm thick.

Now you cut out the four chord patterns out of for example thin (3 mm) plywood with holes in them to fix these patterns including 7° setting angle and the leading edge 15 mm above the bottom of the model , shown also in fig.1.

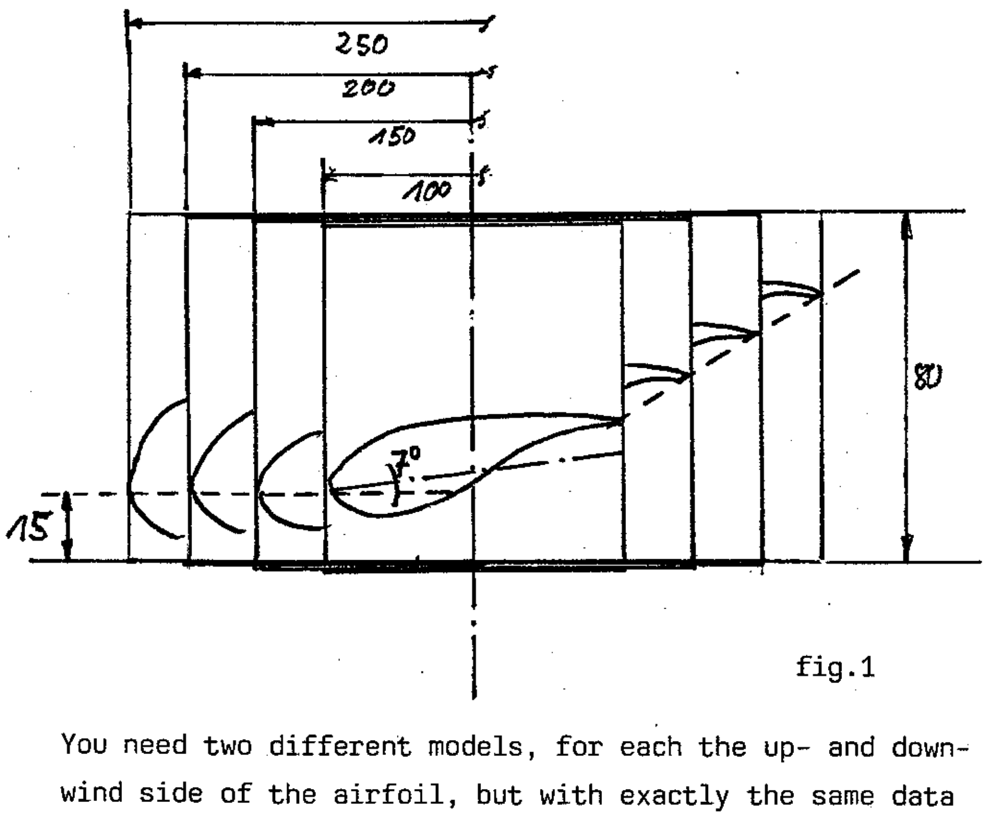


fig.1

You need two different models, for each the up- and down-wind side of the airfoil, but with exactly the same data shown before. To get it clear, see fig. 2 .

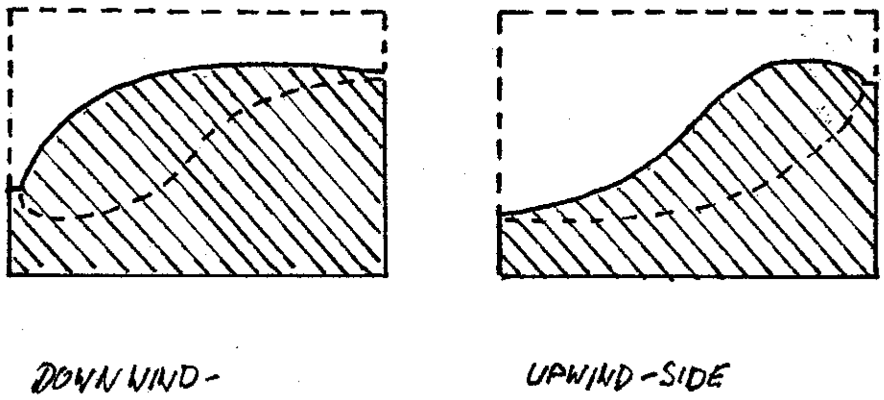


fig. 2

The system of cutting uses the ability of this foam of melting at a temperature of approximately 300 °C. I designed a device to cut the foam with a hot wire which is tensioned by a big spring or a weight and heated up by around 13- 16 A current at a voltage of 12 V DC. The wire is borrowed from a MIG-welding machine and has a diameter of 1.0 mm. An advantage of this wire is it´s strength and low cost. It is protected from to much current by a resistor, wound of constanthane-wire, 0.8mm, 0.6 m long. The resistance is roughly 1.6 Ohms, but should be tested experimentally by changing the length of the wire , which is woung around a tile-brick to dissipate the heat. Power-supply is either a strong battery-charger or a set of lead-accumulatores 12 V. Because the length of the wire varies with it´s temperature, you need a device to keep the tension put onto the wire by a screw with a winged nut, within a minimal limit, because a bended wire does not cut properly. To measure the tension, place a Newtonmeter in the middle of the wire and trie to bend the wire roughly 1 cm by pulling on the Newtonmeter. The meter should show around 30 N when the wire is hot. To find the correct cutting-temperature, look carefullyat the remains left on the wire after cutting some foam. It should boil and burn away itself within several seconds. But also the wire should not be too hot, because then it cuts to wide slots into the foam, falsifying the airfoil shape. The slot should not be more wide than 3 mm.

The correct cutting -temperature is also very important for the surface-quality: too hot wire makes holes, too cold wire makes unstraight cuttings with a bended wire and a rough surface. The surface-quality is also being influenced by the cutting speed. It takes a little time to experience the right speed, too high speed makes the wire bending and, maybe, breaking, whereas too slow speed melts away too much foam. It is also very necessary to work with the same speed at both ends of the model.

To control this and a proper alining, you better work with two persons, one on each side, synchronizing cutting speed. Now you may get a problem: two different chord-lengthes mean two diffenent cutting-times, having the same speed. Therefor fix a small list of wood with nails or pins to the trailing edge of the model. The one cutter with the smaller chord finishes the airfoil pattern first and leads the wire straight and carefully along the list while the other one finishes his profile without panic. The result (after some few training-wings) can be a proper surface, without carvings, waves or holes. A little wavelike (plus-material) surface can be equalised with sandpaper, also the edges should be sanded or grinded.

For the center of the wing, the region close to and in the hub, the aerodynamic profile is matched to the rectangular cross-section needed for the flange. For this you cut off around 300 mm from the inner radius model, replacing it with a rectangular piece, 300 times 250 times 80 mm big. This is brought into a slow and smooth matching by, for example, a handgrinder and sandpaper. The result should be a run-out which can lead all forces from the wing into the root and the hub. To prevent fatigue and overstress, do not make sharp bendings and edges. This zone also needs some optical attension to make it look attractive.

After that, glue all the sections together, straight and fitting close. A good glue for that purpose is polyurethane-glue, which is expanding and also filling holes.
A list of wood, 20 mm thick shall also be glued onto the side of the trailing edge to protect it from compression by the sensor roll of the machine and to make it stronger generally.
Don´t forget to wear a gasmask during cutting the foam, because the fumes are toxic. Work carefully and exact, because you will find each mistake you make on the model also later on the wings. Don´t give up too soon, it takes a littlebit experience to work with the heatwire and to understand all things about modelling.

Chapter 2.
The laminated beam

Laminated wood is applied for the wings of the FC 4000 windmotor. This gives strength and flexibility with an ecologically proper and quite cheap material, because pinewood of normal quality is used. Trees must stand forces similar to forces acting on a windmill- rotorblade during all their lifetime of many decades. In fact, food is not that sensitive against fatigue. Other materials, also glasfiber-polyester, are. After being used on a windmill, the blades can be recycled and made to fibrewood . So you can prevent toxic waste. The disadvantages of wood are the weight and the price.
The quality of the applied pinewood should be of strength-class 40, with equal streak and rather few knotholes.
Only dry wood with a humidity of 10-15% and stored long enough can give good results. A special glue is applied, professionals use it also for laminated timber . Two-component phenolic glue is a 100% waterproof, darkbrown and, thats a petty, toxic in use. When working with it, follow producer´s safety advices.

To safe material, the raw wing before placing it onto the table of the machine, is built tapered in a form close to the finished wing. In this way it is possible to save 60 % or more costs for material. But lamination and preparation is also a little bit more complicated. On the other side, the machine is stressed less and can cut the wing faster.
I have chosen the tapered beam because of saving wood and glue, sawdust and machining-time.
The beam of the FC-4000 rotor is glued together out of boards 1" thick, at least 4" wide and 4.2 m long(standard).
The boards are then planned down to a thichness of 22 mm and brought into form like this:

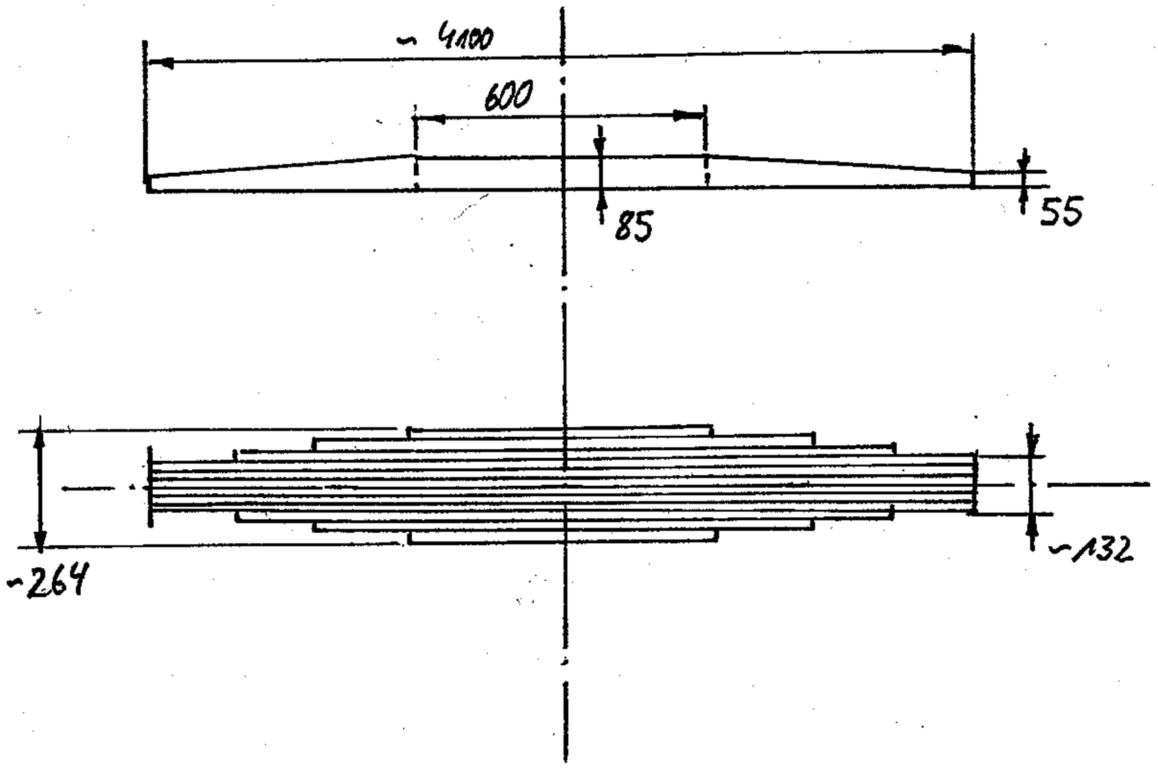


fig.3

The single boards, after planning, can be brought into this form by a circular saw, being quite effective.

For lamination, a special princip and device isused, pressing the single, glue spreaded boarde onto each other by air pressure. Therefor we used a frame of profile-iron shown in fig.4 . The pressure is performed by a fire-hose, closed on one side and an adaptor for a pressure-regulator and the air-hose fit on the other side. The frame first is filled with the wood, kept in position by small lists of wood, then a piece of timber for leading the forces, then the firehose is brought into position. For counteracting the pressure forces of approximately 25 tons altogether, a profile-iron like the one in the bottom (120 x 80 mm) is laid on the staple, locked by steel-bars, 20 mm diameter. After controlling all elements, slowly put the air-pressure onto the system up to 5 bars atmospheric over-pressure. 5 Bars means a pressure of 50 t/m² which must be handled carefully and safety.

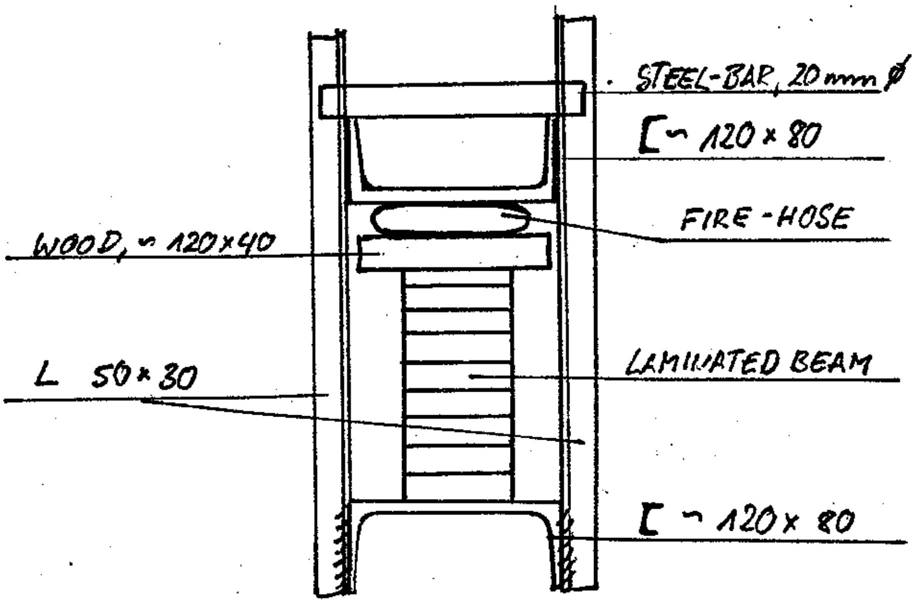


fig. 4

The frame is a little bit longer than 4,1 m, the profiles L 50 x 30 mm are welded on in a distance of 500 mm.

Normally it takes around 24 houres until the glue is dry, at a temperature of 30 °C. The warmer, the faster the lamination will go on. For glueing, a special room with the lamination frame installed and a temperature warm enough is a big advantage. Also the room should be equipped with with a good ventilation to keep away the toxic fumes from the laborator. After glueing and removing the beam from the the lamination device, it must be brought into shape, following the data in fig. 5 .

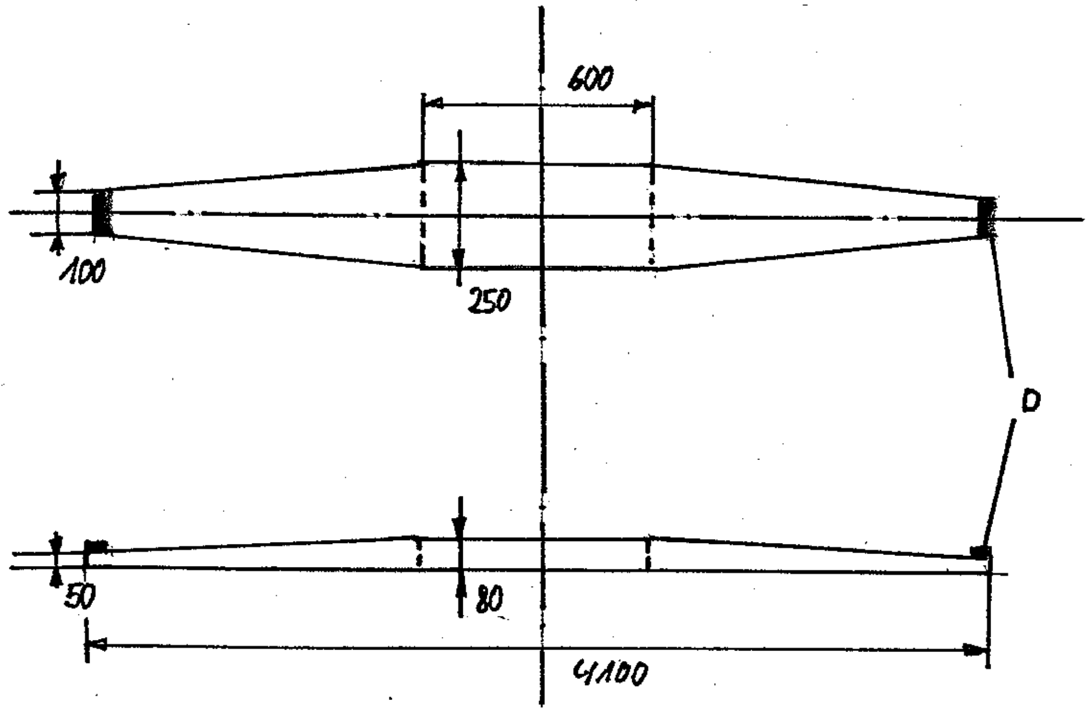


fig.5

It is necessary to plan the untapered flat side, the upwind side, so that a good positon without rocking on the table is possible. On the other side, the downwind side, fix some pieces of wood 100 x 30 x 50 mm, marked "D" on fig.5 , to be able to mount the raw beam properly on the machine-table. Also drill holes through "D" and the ends of the wing, diameter 5-6 mm, for fixing with screws.

When fixing the beam / the models on the table, always follow the centrelines, painted onto the table in a distance of 350 mm, with high accuracy. A millimetre difference can make a profile not able to work as a windmill wing at all.

Chapter 3.
The machine

Before I briefly explained the princip of the machine. Here now you please read more about construction details, function and maintenance. The chapter is divided in single describtions of each assembly-group.

The table

The machine, that means the moving part of it, called machine-frame or wagon, rolls on a kind of a table which also carries the foam-model and the wooden beam. The table is (in this case, that means especially for the production of FC-4000 wings), 5000 mm long, has a width of 900 mm and a height of approximately 1 m. The height should be chosen to be most comfortable to work on, the length depends on the length of the wing, it is calculated to length + 1000 mm. Maybe the width should be chosen to be more, you´ll later see why. There are furthermore two rails on each each edge of the table, made of angle iron 50 x 50 mm, carrying the wagon on four wheels and equipped with stoppers on each end. In this case we made the table out of fibrewood plates, 22 mm thich. the plates are screwed together and stiffened with extra plates. In the bottom you find altogether six feet, made from bolts M 20 and nuts welded on flat iron. You can adjust the length of each leg by turning the bolt. So it is possible to put up the machine on a not very plane floor in a horizontalposition.At last, during construction don´t forget, that the table needs quite a big strength and stiffness inspite of the machine´s weight of roughly 200 kg. Furtheron, t e table´s surface must be very plane and straight to have a proper fixing of the models and the beam.

The machine-frame

The machine-frame, or wagon, carries all equipment such as motors, parallelogram arms, controlparts and the sawdust sucking device. It is welded together from angular iron 50 x 50 mm and forms a nearly square frame 900 x 1000 mm.
On the four edges small roller wheels on legs are bolted on, so that the frame can roll over the table in a height of around 220 mm. This is also the maximal thickness the machine can work, at least in theory, becausesome other factors are now keeping the operating area down to120 mm.
The frame is stiffened with some bracings in the corners.
On one side, on the right when you stand in operating position,there are welded on the two supporters for the up- and down-parallelogram. They are also stiffened and made quite strong. On this side you will also find a platform for bolting on the gearmotor for the stepwise movement on the rails. Crosswards to this, on the other side and on the left, a standard sawdust-sucker is mounted. You´ll also find counterweights welded into the construction, keeping the center of gravity right in the middle of the frame.
It is important, that the weight of all components is balanced to have a save and well performance. During developement, the machine and also the frame changed it´s face several times, so it maybe would be better to modify the frame and it´s construction for the next type of machine.
It should also be a frame wide enough for an overlapping machining of wings, because therefor you need a distance between rails and models (or wing) and between model

and wing of at least 200 mm. That means that I would build the machine-table 1200 mm wide instead of 900 mm , next time. This is also seen only for FC-4000 wings with a maximal chordlength of 250 mm.

The sensor roll

The sensor roll´s role is, to feel the surface of the hard foam model and give the included airfoil-data mechanically over a parallelogram-system to the tool-set, which machines the wooden beam. There are some necessaryties: first the roll should have enough friction on the model, then it should have good bearings and a shaft rolling precise and without excentricity. Also it should have a comfortable grip and the possibility for adjustment. The roll is in this case made of fibre-wood, three boards laminated on each other, giving a thickness of 48 mm. This thickness is necessary, because otherwise the roll would sink into the the foam of the models, falsifying the airfoil and destroying the model. Also the roll has a radius a little bigger than the one of the sawblades of the toolset. I have choosen 166 mm diameter, which makes 1 mm extra for the model´s inaccuracy, depending on the heat-wire melting away too much material, and 2 mm left on the machined wing for surface work such as grinding and sanding. Also the little roughness from machining can be equalized. The sawblades have a diameter of 160 mm.
The grip has a built-in microswitch, I will later describe this part belonging to the security system. The grip is placed above the roll on the sensor-roll arm, a part of the two pendular arms-system forming the left-and right parallelogram and carrying also the tool-set and sawmotor.
The sensor-roll arm consists of the upper bearing, the upper tube with two adjustment-umbrakobolt, the lower tube is carrying the roll itself on two roller bearings, the

grip and the joint for the connection-rod. It takes some experience to find the exact placement for the grip, for example, because it must fit into the geometry of both the machine and the man working on it.

The set of tools , motor and transmission

We have choosen standard sawblades of circular saws for use in the copying-machine, because they are cheap, well available and the sensor-roll can be dimensioned in a good way, taking care of the sensitive foam-models.
Then, the first prototype´s tool-set was mounted on a simple shop-saw which made the whole construction very plain, and inone way, smart. But rather quick this shopsaw showed it´s unsuitability, because though it was a 800 W-type, it became hot quite fast and also the brushes of the tiny one-phase slipring-motor wore out. There was also no satisfactioable solution for the sawdustsucking and the cutting-depth was not enough.
So after a short test-period, when the entire machine showed it´s function properly, I decided to change the tool-set and the transmission. Looking for a standard or semi-standard part, I found an angular-milling-unit delivered by a company in Aarhus, but ti´s delivering time was too long to take account. Maybe there will be a possibility for the next type of machine to find a standard part used for special-application-machines.
The only way was to design a unit of a 2.2 kW, three-phase asynchronous motor with squirrel cage, av-belt, a standard bearing-unit and the set of sawblades. The whole system is mounted on a 1 1/2 " tube with a cover for the sawblades forming the sucking piece of the sawdust-fan, and the upper bearing, which is similar to the sensor-roll´s.
The tube has two supports, one on each end, for once the bearing unit and twice the motor, whereas the last one works as a tightening-device for the v-belt. The other side of the connection-rod, see "sensor-roll", is also mounted onto the tube. A cover is mounted over the v-belt,

which is a special one: with itŝ teeth it is able to roll on wheels of a diameter of 50 mm. This small diameter, also to find on the bearing-house, is very necessary to keep a cutting-depth of more than 50 mm. This depth is needed for the parts of the FC-4000-wing colsed to the hub, where it is arched the most. For this reason I would also like more a bearing unit shorter than the one used here (260 mm) , to be able to work in a bigger angle of arching.

The special design with two or more sawblades on the sawing-shaft needed a special support or lock to fasten the blades. Therefor I turned the diameter of the shaft down to 20 mm and changed also the discs which keep the blades on the shaft by friction. A 12mm-nut is now locking the whole thing.

Between the singlr sawblades small distance-rings are mounted which keep the teeth of the blades on a distance of 0.4 to 0.6 mm. I think it is possible to work with about 3 or 4 blades on the shaft. More blades will need more power ond perform a worse surface-quality on the arched parts of the wing close to the hub. There the surface will look more stepwise than now.

It will also be interesting to experiment with rolling blades, where the blade is not plane but mounted in a supporter having less than 90° to the shaft axis. This blade sways from side to side, I don´t know about the surface-quality. Also the application of milling-wheels is an interesting thing, because then you can choose between lots of forms and designs. Another fact is, that milling wheels, especially those with interchangeable hard-metal-bits, are much more expensive. But when you think of a commercial application, this tools have shown steadiness in the window-fabrication.

Parallelogram,counterweight and equipment-carrier

This is a very necessary part of the machine, because all moving parts are interconnected through it. It carries the tool-set and the sensor-roll and is fixed to the frame.
A system of a counterweight is keeping it in suspense, so that you don´t need more forces than these to overcome the friction in the single parts of the system.
The parallelogram, which makes a movement up and down and keeps it´s shorter side (the equipment carrier) vertically,is made out of four tubes 3/4". Each tube has got two bearing-caseswelded on each side. The axis of the bearings is turned 90° to the axis of the tube. Both bearing-cases are parallel and made ofround steel bars of 30 mm diameter, bored 12 mm. The bearings can be very simple bearings, I have chosen greased steel-on-steel bearings, although the complete parallelogrammay not have any play to perform well. The two upper and the two lower tubes are interconnectedwith each one or two tubes 1" to eliminate torsion.
Torsion in the parallelogram means unexactness in machining the wing, because the tool-set can have a different level above the table than the sensor-roll.
Each bearing can be lubricated for service with a greaser.
The counterpart of the bearing-cases is a shaft of stainless steel, 12 mm diameter, welded between two flat pieces of steel on a frame fixed to the equipment-carrier and the machine-frame. This construction is very simple and cheap, but can of course also be made out of standard bearings, but you should keep in sight, that the bearings must perform a little friction to keep the suspense and to equalize the movement of the sensor-roll and the tool.
The suspense is kept by a counterweight hanging on a bicyclechain led over two chain-pulleys to the equipment-carrier, the outer part of the parallelogram. The first pulley, an old bicycle bag-hub, leads the chain from vertical to horizontal position onto the second pulley, which is a reconstructed bicycle pedal-bearing with two gearwheels,

one small and one twice as big. In this way you have a translation and the counterweight can be half of it´s weight without translation, but must run twice the way, that means 240 mm instead of 120 mm, the distance of the operation area above the table. The counterweight itself is mounted on the right of the frame, hanging on the bicydle-chain. Pendulating during moving the machine is prevented by a thin steel-rod which is leading the counterweight of 22 kg on it´s way up and down.
The equipment-carrier consists of two horizontal plates welded onto the top of the left parallelogram-frame.
This frame itself is rectangular, welded together out of square tubes 50 x 25 mm and angle-iron profiles. The horizontal plates have longholes crosswards to the longholes in the bearing-cases of the tool-set- and sensor-roll-upper bearings. These bearing-cases are fixed on the horizontal plates with bolts, so that the bearings and the arms are adjustable in each direction.
The distance of the two bearing-cases is 350 mm $\pm$ 0.5 mm, the tool and the sensor-roll and the two centerlines on the table have exactly the same distance.
The set of sawblades shall be adjusted to be in the middle of the censor-roll´s distance from the machine´s side.

The sawdust system

To suck away the sawdust from the table and to collect it, I installed a standard sawdust-sucking ventilator, normally applied for wood-toolmachines, such as planners, circular saws or milling machines. The blower-motor´s power is something like 750 W, the hose to the sawblade-cover has got a diameter of 120mm, later reduced to 100 mm. A flexible hose for ventilation systems is used. Though I tried half a dozen designs to catch the sawdust, the rate of caught sawdust is still roughly 50%. That is not too much, but I hope, the system can be improved by using better components. If you imagine, that each wing delivers up to 20 kg of sawdust, half of it lying around on the machine components is not very comfortable. Especially, when sawdust is lying on the models,it can cause problems.

The feeding system

To feed the wagon during machining, theat means to move thewagon stepwise or continuosly over the table, the machine is equipped with a gearmotor, which is giving it´s torque via a second chain-translation to a chain fixed on the table parallely to one rail. The adjustable gearmotor runs at it´s minimal number of revolutions , 22 RPM, together with the second translation, which is also including the driving-shaft, the feeding speed issomething like 1.5 cm/sec. The driving shaft is coupled to the gearwheel with a secirity-pin, breaking when the torque exceeds, for example in case of an accident . The stepwise feed is controlled by a timer, adjustable andswitched by a small button in the right hand-grip. Pressing this button a little bit longer than the feeding goes on, the timer switches the relais always the same time, for example 0.5 sec for the feed of 8 mm, when the machine is equipped with a set of two sawblades. The timer is built into the control-box on the bagside of the machine-frame. To feed continuosly, two green buttons are installed on the small controlbox in the front. To move the wagon, press these buttons continuosly. Endstop-switches guarantee tobrake feedin at each end of the table. The chain can be tightened on one end of the table, it shall be kept roughly clean, a little bit of sawdust inbetween the sections of the chain does not matter too much. Also controll the chain-guide below the small chainwheel.

The control-unit

All controlling equipment is built into the control-box on the otherside of the machine, The small box in the front includes four switches, all other switches are placed around the frame, the cables are led in channels or flexible tubes. In the control-box (see fig. 6) you find the connection to the mains via fuses 3 x 10 A, 400 V, a transformer 380/24 V and a rectifier for the supply of the relais, four relais to control the three three-phased motors, the timer-unit and connection-terminals for high voltage, bottom, and for low-voltage, right side. The low voltage curcuit is for all switches in the control- and security-system, the high voltage circuits are coupling the motors and the mains.

The security-systems

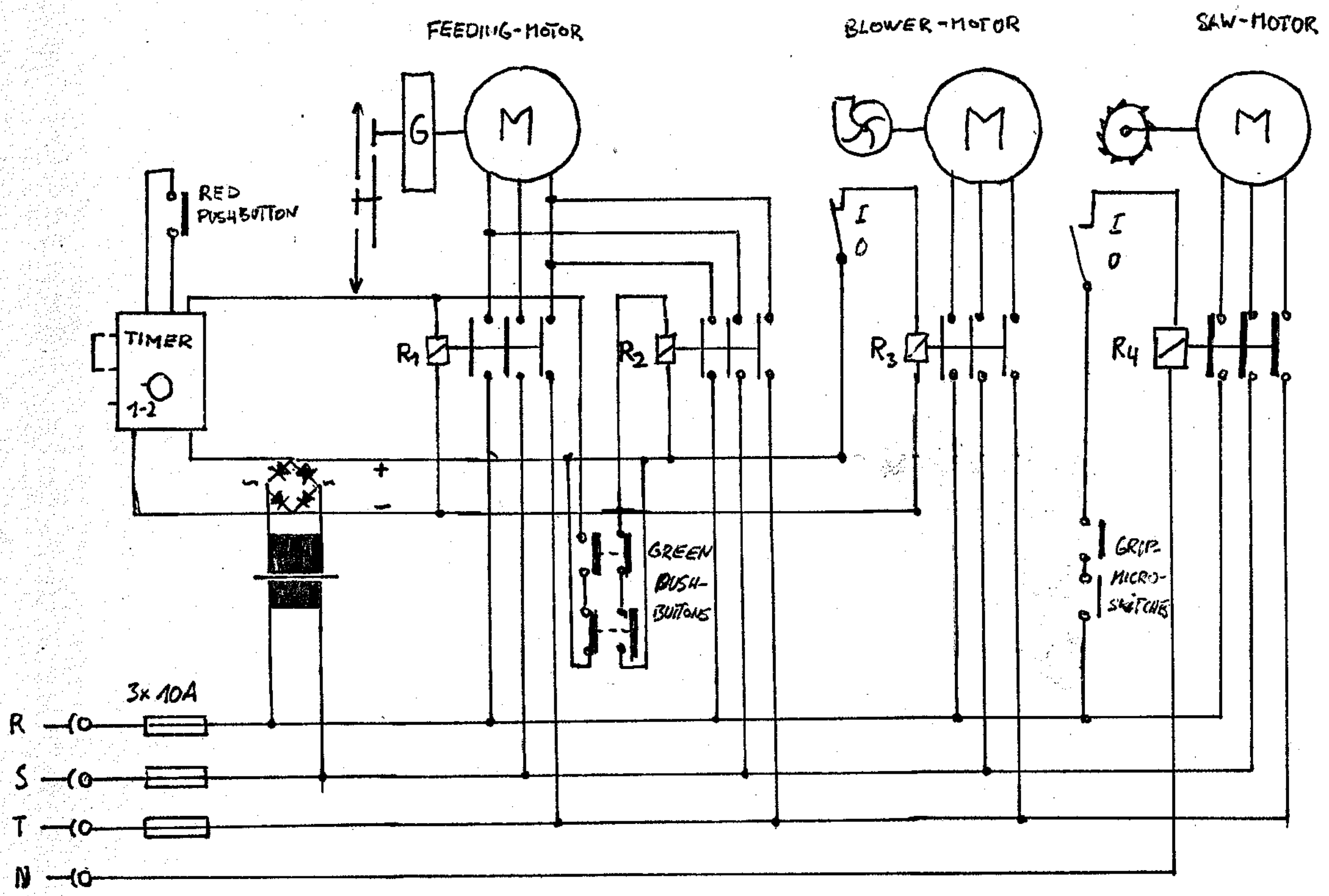
To make the machine more safe in handling, after the first tests I installed some security-systems protecting the worker from harms and the machine from damages.
First, the sawmotor of 2.2 kW can only be kept running by switching on the mainswitch on the small control-box and putting on both hands onto the grips. In the grips are two microswitches built in, connected in line. Then there is a protector on the frame, kepping the sawblades off from cutting into the frame. Furthermore, the feeding-motor is controlled by the two endstop-switches, preventing the wagon from falling down thetable. Manual feeding is only possible with pressing one of the pushbuttons continuosly. Then you have shelters over v-belt- and chainrives, also over the toolset and all electric components are covered or / and converted to low-voltage. By standing in the normal operating-position you are kept away from all other moving parts.
At last it is left to say, that this manual should be read carefully, maybe a special user´s manual shall be made in

Danish. All machines like this can be harmful, advices shall be followed and taught carefully. The fact, that this machine is new-designed and still in a prototype-stadiun, shall be considered when working with it.

Working with the machine

Most of the things for this chapter are named in the forerunning chapters, here I´ll give a brief describtion of the working process.
After fixing models and wooden beam on the table, control the single parts of the machine, especially the locking of the tools, the distances of the pendular arms (350 mm), the function of all security switches.
Then move the wagon to the left side of the table by pressing the left green pushbutton continuosly, until the set of tools is above the radius of 2000 mm. Then switch on the sawdust-blower with the left switch on the small box, controlling density and operating of the system. Then switch on the sawmotor´s mainswitch and put both hands onto the grips, tightly but elastic, because the motor gives a small shock towards the operator. Because of a little play in the feeding-device, caused by the secuity-pin, you must press the right green pushbutton until the wagon begins to move in operating positon.
Now carefully put the sensor-rollonto the foam-model, watching how the sawblades move through the laminated wood. Follow the complete profile til the trailing-edge, then lift the roll and while moving it back into starting-position, press the small red pushbutton about 2 seconds to feed the machine one width of the tool-set more to the right.Begin again with the cutting process. It takes also here a little experience to get the "feeling" for the dynamics of the machine. Got to the end of the first side of the wing, turn the wing and take theother model back to the left. Move the machine bach to the left side and start

again. Nornally it does not matter too much, if you start with the up- or down-wind-side of the airfoil; Istarted with the downwindside and have no experience starting the other way. When machining the upwind-side, don't forget to put some pieces of wood under the hollow beam to prevent bending and vibrating.
After cutting the two faces of the wing, remove it from the table, cut off the unmachined ends and begin the finishing. Form the leading edge with the help of patterns and take a rough grinding to equalize rugh humps and to form the roots of the wing. In this stadium also control the balance by putting a 6 mm steel-rod through a hole in the center. Round the tips and plane the region of the hub, where the flange and the airbrake is mounted. Then take a sanding-machine and make the surface smooth slightly without falsifying the profile. In the end, fill small holes with plastic padding and prepare the wing for painting. Also drill in the four holes for the hub, 20 mm diameter and press in the stainless-steel tubes, 20 x 16 x 81 mm. Varnishing of the wing can be done with two-component epoxy- laquer or something similar, the leading edges must be protected from erosion .


FEEDING-MOTOR
BLOWER-MOTOR
SAW-MOTOR
M
M
M
G
RED
PUSHBUTTON
TIMER
1-2
R1
R2
R3
R4
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0
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PUSH-
BUTTONS
GRIP-
MICRO-
SWITCHES
3x 10A
R
S
T
N